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PUBLIC WATERING STATIONS.

BY FRANK E. MERRILL, WATER COMMISSIONER, SOMERVILLE, MASS.

[*Read September 11, 1914.*]

For some years past there has been in our mind a growing feeling that some better method of public horse watering than that in common use might be devised. This led last year to some experimental work along the line of individual, or pail, watering, and early this year was crystalized into definite form when an earnest appeal was received from the Department of Animal Industry of the State of Massachusetts, supported by our local board of health, for our coöperation in their effort to stamp out the rapidly spreading disease of glanders, by closing all our public horse-troughs. They requested at the same time that we furnish faucet supplies, or some like form of service, so that the horses might not suffer from lack of water.

The request fell into soil made fairly fertile by our earlier considerations of the subject, and it was but a short time before the few open public horse-troughs that we had in the city were closed—whether to remain so or not depends upon the successful operation of the individual pail system which we are now trying out.

Is the system likely to prove successful? An impartial consideration of the whole matter leads one to the conclusion that there is something to be said on both sides of the question.

I am informed by the Commissioner of the Massachusetts Department of Animal Industry and by our own board of health that the number of cases of glanders has largely decreased since open horse-troughs in our own and neighboring cities have been

closed, and it may therefore fairly be presumed that the primary object desired, the stamping out of this disease, is being assisted thereby. The proportion of this decrease in the disease rate that is solely due to the closing of the open horse-troughs may be admitted to be somewhat problematical. It would be perhaps fair to assume that some of the progress made in the reduction of the disease is attributable to a more thorough inspection and cleaning of stables and blacksmith shops, and to the difficulty of bringing horses into the state from certain directions that do not possess a clean bill of health.

The tendency of a horse to rub his nose against a watering-trough, and the possibility of a well animal becoming infected therefrom, would seem to be avoided if the structure or the conditions of its use were such as to cause the animal's head to be kept away from it.

It is probable that ninety-nine per cent. of the quantity of water flowing through the ordinary open trough serves no useful purpose, and is therefore wasted. In troughs where the flow is controlled by a ball-cock this does not, of course, apply. In the pail-watering system the waste is practically eliminated. The value of the water wasted in running troughs varies according to local conditions. In Somerville it has not been great, as the number of troughs has been small and the flow of water through them has been closely regulated. In some cities I have observed, however, that the flow is very large, — quite unnecessarily so for the object to be attained, — and the money value of the water thus wasted must reach quite a large figure.

In expression of gallons per capita the waste of water from the open troughs in Somerville would undoubtedly be but a small fraction of one, probably less than one quarter and possibly as low as one tenth. In terms of dollars and cents, a reduction of one gallon per capita daily in our water consumption means a saving in our metropolitan water assessment of $1 250 for the year, and the cost to our city on the above basis for water thus wasted would be, therefore, less than $300 per year. Not a large sum, to be sure, yet one to be saved if what it represents is of no real benefit. From observations of the flow of water through troughs in some cities it would seem as though the waste, figured

on the same basis, must reach into thousands instead of hundreds of dollars.

The large size of the common open trough restricts its installation in congested districts to comparatively few localities, such as public squares, wide streets, or similar open spaces. This tends to keep the number of horse-watering opportunities comparatively small. Some method of watering that is inexpensive in its construction, occupies but little room, and that can be installed in a city sidewalk at frequent intervals, would seem, therefore, to possess distinct advantages.

While the application of faucets to fire hydrants for such purpose is a simple and easy way of furnishing individual supplies in a sufficient frequency, I do not feel that this use of the fire service of a city is to be commended, especially if the hydrants are not equipped with outlet valves, and should regard this method as a temporary expedient only.

I suppose that no watering device is so pleasing to the lazy driver as the common open trough, where he can sit at leisure enjoying his pipe while his tired and perhaps overheated horse drinks from the flowing bowl to his heart's content and quite possibly to his stomach's detriment.

There is a probability that the danger of overwatering horses on hot days, causing colic and indigestion, is largely averted by the pail system, and possibly as much distress is saved the animals in this way as is caused by the failure of drivers to offer them water when it is needed.

This laxity on the part of some drivers to water their horses on account of the extra effort involved on their part is advanced as an argument against the adoption of the pail system, but it would seem that the city or town had done its part when it willingly furnished an abundance of water for the animals without cost, and it should not be expected that in addition it should furnish means whereby a lazy teamster may do his duty without any exertion on his own part.

But observation shows that the watering stations in Somerville are largely patronized and are appreciated by teamsters, and we may hope that the number of drivers who will not exert themselves sufficiently to attend to the needs of the animals in their charge

at these convenient stations is very small, and that the class will soon become obsolete as the new habit is acquired.

The new public watering stations in Somerville are an experiment, and the object of this paper is to bring them before you as a suggestion of what may be done along this line rather than to lay any particular claim to their efficiency as a new departure.

The keynote of the Somerville watering-station construction is "simplicity." This device may be described as being in its essential parts a piece of 12-in. cast-iron pipe set in the ground with its bell-end upwards, the face of the bell being 29 in. above the sidewalk grade and the other end being a sufficient distance below the surface to obtain stability. An ordinary service pipe from the street main makes into a 2-in. riser which comes up through the center of the standard and is held in position by a cast-iron strainer resting in the bell of the large pipe. This riser is capped with a side-outlet cross standing 12 in. above the top of the bell end of the pipe, which forms a convenient ledge upon which to rest a pail while filling. Into one of the outlets of the cross is inserted a $\frac{3}{4}$-in. self-closing hose bibb, so that a hose line may be attached if needed for any purpose; into two other outlets are inserted self-closing plain bibbs, and into the outlet facing the sidewalk is fitted a bubbler controlled by a self-closing cock. In this condensed space there are found, therefore, opportunities at once for three teamsters to draw water and for another one to obtain a refreshing draft for himself.

Attached to the side of the 12-in. standard near the sidewalk grade is a bowl for dogs, which is kept supplied with fresh water by the drip of the bubbler overhead, the water being caught in a tunnel set underneath the strainer and conveyed through a small pipe into the dog bowl.

The waste from the faucets and dog bowl is discharged into the interior of the 12-in. standard, which has a cement bottom, and an opening allows the water to escape into a drain pipe leading to the sewer, or if preferred into the gutter.

On the side of the 12-in. standard under the bubbler is fastened a step at a convenient height for children to reach the water from that fixture.

All the materials used in the construction of this watering sta-

PLATE III.
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MERRILL ON
WATERING STATIONS.

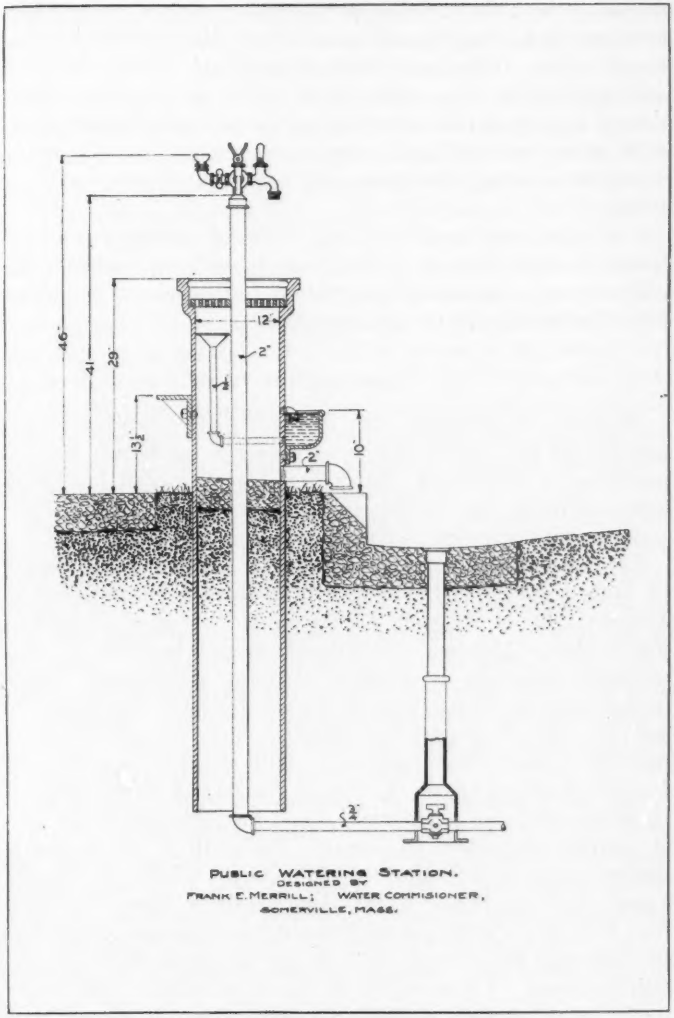

46"
41"
29"
13½"
12"
2"
1"
2"
10"
¾"
PUBLIC WATERING STATION.
DESIGNED BY
FRANK E. MERRILL; WATER COMMISIONER,
SOMERVILLE, MASS.

FIG. 1.

tion are — with the exception of the castings for the strainer, dog bowl, and step — such as are found in every water-works shop or supply house. The cost of the outfit made up in your own shop and ready to set in position will be found to be about twenty dollars, and if you add as much more for the cost of installing it, with supply and drainage connections, you will have a pretty complete watering combination at a very moderate outlay of money.

I feel that I can speak with some degree of assurance as to the simplicity and low cost of this form of watering station. Its efficiency as a horse-watering proposition is perhaps yet to be fully demonstrated in my own experience.

DISCUSSION.

MR. FRED F. WALKER.* *Mr. President and Gentlemen,* — I am grateful for this opportunity to express in a public way my appreciation of the hearty coöperation that has been invariably extended to me by the officials who have charge of the water systems that supply the citizens of the Commonwealth.

The state department I have the honor to represent is charged by statute law with the control of contagious diseases among animals. One of the most serious diseases we have to contend with is that of glanders. This deadly malady had prior to 1913 assumed, especially in Boston, alarming proportions. Early in that year the Department of Animal Industry undertook the arduous task of bringing the epizoötic under control. Various remedial measures were inaugurated with but indifferent success. In spite of all our efforts the disease remained a serious menace. Glanders was being communicated and was spreading in the face of sanitary preventive treatment. The truth of the matter is that we were not getting at the source of the trouble, and finally I petitioned the Public Works Department of Boston for relief from that device, most uniformly dreaded as a spreader of glanders by those who are in a position to know, the public drinking-fountain for horses. I was referred by the public works commissioner to the superintendent of the water department, by whom I was

* Commissioner of Animal Industry, Massachusetts.

extended every courtesy, and together we evolved a plan by which the danger of spreading the disease should by minimized, and at the same time the comfort of the animal assured.

The plan was the simple one of closing the flowing drinking-fountain, and installing an auxiliary tap so that drivers, by the use of their own pails, might supply water to the horses in their charge while on the streets. This regulation finds its counterpart in the antiseptic cups required in railroad trains, in the " bubbler fountains " now so generally in use in school rooms and in the streets, and in the order dispensing with the open faucet in public places. It is but another proof, and a practical one, of the old-time saying, " An ounce of prevention is worth a pound of cure." Not only are we aiding in checking the spread of this disease by closing the fountains, but we are also doing the horse another favor and, incidentally, his owner, for in place of the horse when heated drinking too much, by the use of the pail he is kept from extreme indulgence and thus avoids the danger of digestive troubles so generally prevalent during the heated term.

The coöperation and courtesy shown by the water officials of Boston have been duplicated by similar officials in most of the cities and towns in Greater Boston, until practically everywhere within the metropolitan district this preventive measure is in force and operative, with satisfactory results as you shall see a little later. This is no fad of mine. In this work for man and beast — for glanders may be communicated to the human as well as the animal — the personal equation is absent. We are working to advance the health standard, and we know no better way than to use every known means of prevention.

But nothing is done in connection with this work I can assure you, until it has been carefully considered by expert authorities. The decision to close the public drinking-fountains or open troughs was the logical conviction born of the department's experience which was supported and approved by the most eminent authorities in veterinary science in the United States.

During all the time the flowing fountains have been closed, I have not received a single protest from a horse-owner. On the contrary, I have had the most flattering endorsement of my policy from the largest and most representive team-owning firms in

Boston, as well as a letter of commendation from the largest organized body of horse owners in the state, and hundreds of approving messages from men owning only a few horses but equally interested in the health of their animals.

And while on this point let me name a few of my many advisers, — men who are of national if not world-wide reputation on this subject. I am permitted to include in my advisory staff Prof. Theobald Smith, professor of comparative pathology, Harvard University Medical School; Prof. V. A. Moore, director of New York State Veterinary College at Cornell University, Ithaca, N. Y.; Dr. A. D. Melvin, chief of the United States Bureau of Animal Industry, Washington, D. C.; Dr. C. J. Marshall, state veterinarian, Live Stock Sanitary Board of Pennsylvania; Dr. J. G. Wills, chief veterinarian, State of New York Department of Agriculture.

The plan has not been in vogue very long, but I am sure you will agree with me that the results are most encouraging. The flowing fountains in Boston were closed November 1, 1913. From December 1, 1912, to September 1, 1913, there were 401 cases of glanders in the city of Boston; the horses were either killed or died. From December 1, 1913, a month after the order went into effect, until September 1, 1914, only 262 cases were of record, a decrease of 139 cases. If we had simply prevented an increase of the cases reported in 1912, we should have been justified in feeling that we had put an effective check upon the disease, but when we were able to reduce the cases in nine months almost 35 per cent., we naturally are confirmed in our estimate of the effectiveness of the step.

In closing I wish to say that any and all of you, who can spare the time, will be welcomed at the department headquarters in the State House. I shall be happy to place before you the records of the office in relation to glanders control, and to show you the originals of the letters I have received favoring the individual drinking pail for horses in infected areas.

THE PRESIDENT. I think I can safely assure Mr. Walker that water-works people as a whole are willing to help him in this great work of disease prevention in no matter what line. They have taken up the matter of water sanitation, and they are willing, I

believe, to take up the matter of sanitation from outside sources other than water itself. This device of Mr. Merrill's shows the interest that water-works people take in those things when asked to coöperate with those that want to stimulate that kind of work.

Dr. Francis H. Rowley.* As Mr. Walker said, the point where his department of the state came into contact with your own is where the horse is the interested subject. Now, that is just where our point of contact also is made with your organization. However mistaken I may be in the attitude I take, you surely will not accuse me of not being intensely interested in the horse. I am not a veterinarian. I have owned horses, from one to three driving horses, all my life. I have studied them, their anatomy, the inside of them and the outside of them, and have had the personal care of them for years at a time. I have always been observant of horses. So when Mr. Walker came to me last autumn and said, "We are thinking of closing the watering troughs in the city of Boston, for the prevention of the spread of glanders; we would like to know how the Massachusetts Society for the Prevention of Cruelty to Animals feels about it," — well, inasmuch as I had done all that was in my power to do to have this matter of the control of glanders put by the state into Mr. Walker's department, and inasmuch as I was very anxious to have glanders reduced, stamped out, if possible, I said, "Well, as a temporary expedient I have no objections, — the Society will have no objections, — though I thoroughly believe that what we call the sanitary fountain as a source of spreading glanders is so trifling as hardly to be worth consideration." I am led to believe, from all I can learn, that it is the purpose of the department to make this a permanent thing, and, so far as they can, never again to have open watering-troughs in the city of Boston.

Now, I am just as much opposed to the dirty open watering-trough as anybody can be. The city of Boston used to keep two men traveling constantly about the city cleaning out its open watering-troughs, and we were not in the condition of those people in New York City, who complained that the fountains they wanted closed were fountains in front of saloons that spittoons were washed

* President of the Massachusetts Society for the Prevention of Cruelty to Animals.

in in the morning and that children took their baths in, and that dogs and cats were bathed in, because our fountains were kept in a very decently clean condition. The thing that I do believe in is a watering-trough that furnishes horses at every opportunity that they can obtain it good, clean, flowing water, thoroughly believing that water in that condition becomes so trifling a source for the spread of glanders as to be hardly worth consideration. I do realize that the matter of cost — probably more and more as time goes on — will have to be considered by you gentlemen and by our cities. It is very much more economical, I am sure, to water horses by a device of the sort now in use than by the open, flowing bowl. The difficulty is that the average driver will not take the trouble to get off from his seat and take his pail and water his horse. I have taken pains to sit in a place where I could observe fountains in the city of Boston, or the places where these things have been established, and I have not only seen drivers come up and damn the city and everybody else because the fountain was closed, but I have seen them borrow the pails of their fellow-drivers and water their own horses with them, and in some cases — not a few — I have seen them come up, find that there was no water, and though there was a sign there that water could be obtained here at a faucet, drive on their way and let their horses go thirsty.

As to the matter that was spoken of here, the open fountain giving too much water. Now, I think all men who know anything about a horse know that the thing a horse wants is water often; then he never drinks in a large quantity if he is watered frequently. A veterinarian said in my office that a fellow veterinarian said to him, " You are not going to oppose the closing of the fountains, are you? Since the fountains were closed in Boston, I have had more business than in my whole life, because these horses, so many of them going without water through the day, come in at night and drink a barrel full, and about twelve o'clock I am called."

As I said to you, my opinion in this matter isn't that of a veterinarian, but I wrote a letter to every veterinarian in the state of Massachusetts, about three months ago, and I told each of them that our fountains were closed and asked if he would tell

me what his judgment was as a result of his knowledge and his experience as to the wisdom of it, and whether in his judgment more suffering came to the animals from going without water, as they might be deprived of it, or whether more suffering came from having them open and taking the chances of contagion from glanders. Well, I was surprised that, out of 426 letters sent to 426 veterinarians — the list given me by the registry of veterinarians of Massachusetts — every letter enclosing a stamped envelope for reply, only 143 replied. Of these 143 veterinarians of all sorts, — good, bad, and indifferent, — almost 60 per cent. replied that according to their judgment and experience it was a very foolish thing and hard upon the horses to have the fountains closed. So this is not absolutely a matter upon which I am speaking, though a layman, without authority.

I want also to bring you a few other facts concerning our own city. In the first six months of 1909 there were 116 cases of glanders. In the first six months of 1910 there were 157 cases of glanders. In the first six months of 1911, there were 181 cases of glanders. In the first six months of 1912, with the fountains all open and nothing being done in an excessive degree to prevent the spread of the contagion, it dropped to 155. In 1913, the first six months, it rose again to 199, and during the first six months of 1914, — that is, this year, — it has dropped to 166. Now, between 1911 and 1912, taking the first six months of the year, with all our fountains open and no quarantine from outside of Massachusetts against horses coming in here with glanders, and not a great deal being done toward the disinfecting of blacksmiths' shops, we had a fall in those first six months of 26. Now, with the quarantine against New York and Connecticut and Rhode Island, and with orders issued to blacksmiths' shops and others to disinfect their stables, and with all the fountains closed, they only gain 33 cases. So it would not seem, from the statistics, that all the gain had come from the closing of the fountains. I am certainly willing to admit that the average dirty trough, and even the average clean trough, is a possible source of contagion, but that it is the chief source is, I believe, an absurd statement.

Let me quote you from experience abroad. The London Watering Trough Association has been engaged for many years

in watering horses. It waters in the city of London over half a million horses a day. In 1903 they had — I will give round numbers — 2 500 cases of glanders. In 1904 they had 2 600 cases of glanders. In 1905 they had 2 000 cases of glanders. In 1906 they had 2 000. In 1908, 2 400. In 1909, 1 700. In 1910, 1 004. Then in 1911, 502. In 1912, 316. What happened between 1908, when they had 2 400 cases, and 1912, when they were down to 316 cases, the last quarter of that year having in the whole city of London only 24 cases of glanders? Why, the government of Great Britain had introduced the Glanders Act, which recompensed every man in Great Britain who had a glandered horse for his horse when the horse was destroyed. That made it a very much easier thing for the man whose horse had glanders to report his horse and have it destroyed, and it took out of the community a constant source of the spread of the contagion. Of course, the situation is different, very much different here; because we have no national law here, as they have abroad. This is what happens in Massachusetts in I don't know how many cases, — I know personally of some: A veterinarian goes through a man's stable, containing 25 or 30 horses, more or less, and he subjects them to the Maline test, and perhaps, as I know happened in one case, of about 40 horses, nearly half reacted. It was a hard thing to say to that man, " Your horses have got to be destroyed," — eighteen or twenty of these good-looking, fat, sleek, comfortable horses which had reacted to the test. It was not done. Those horses, some of them, are working to-day in the city of Boston, and the authorities know, and a number of us know, that they are horses that have reacted to the Maline test. What are we going to do? Does a veterinarian want to go into your stable, if you have 100 horses and 25 of them reacted, and kill them? Not till the state is willing to pay the man that owns the horse a sufficient recompense so that he will not be tempted to keep his horse or sell it to somebody else. Another thing that happens in the state of Massachusetts is that a man who has a large number of horses, more or less, brings them to the veterinary and has them subjected to the test, — not done under the Bureau of Animal Industry but as a private matter, — and this veterinarian says to his client, " You have six or

eight horses here that react," or a dozen or twenty. What does he do? He proceeds quietly to work them off into the community through sales stables and in other ways. That is a thing that is going on. And up till we had our quarantine we had horses that could be brought in here from many states without any bill of health. And I believe it is possible for them to come in from the West without any bill of health; and, so far as I know, if a man wanted to go into Chicago and buy a carload of horses that in a private stable had reacted and given evidence of being glandered horses, and ship them into Boston, there is nobody to head them off and say, " Where is your bill of health certifying that these horses are in perfectly sound condition? "

Here is the opinion of Professor Hunting, Fellow of the Royal College of Veterinary Surgeons, and inspector of the London County Council. This gentleman says:

" One more method of spread [of glanders] I must refer to — the public water trough. It is rather curious that some men have picked out this most useful institution for special attack. It is quite possible that some cases of glanders have arisen as the direct effect of drinking at a public trough, but they are very few and far between. I have an intimate knowledge of the stables of three contractors who have had during the last twenty years four outbreaks of glanders in their studs. Each outbreak was clearly and directly traceable to the purchase of a horse from an infected stud, and was stamped out at once without spreading. *Save these outbreaks, no glanders has troubled them, and yet their horses travel all over London and drink at any water trough they can reach.* I feel convinced that infection from water troughs is very rare, because in 90 per cent. of all outbreaks which I have personally investigated, other methods of infection are traceable. Even if 5 per cent. of all outbreaks in London were traceable to the water troughs, the gravity of the harm would be no argument in favor of closing the troughs, especially in summer. *The harm resulting to horses from being denied water all day would cause a mortality greater than is caused by all the glanders in the metropolis.* The fact that an occasional case of glanders may be due to public water troughs is an argument for the extermination of the disease, but not for closing the troughs. . . .

" Nothing leads to fatal abdominal diseases in horses more certainly than an irregular and insufficient supply of water.

" Even if it could be shown — *which it cannot* — that the water troughs infect horses with contagious diseases occasionally, the

advantages to hundreds and thousands of horses whose thirst is quenched, and colic prevented, would be an argument for the existence of the troughs."

Watering half a million horses a day in the city of London, as they have been watering now for over twelve years, if the fountain was a great source of spreading this disease you would think that nearly every horse in London ought to have the glanders. Instead of that there has been with this Act such a marked diminution that it looks as though in a few years they would not have a solitary case. When the head of the Animal Department of Canada lectured last winter here at the Harvard Medical School on this question, I spoke with him at the close of the lecture, and he said that they had practically stamped out glanders in Canada. I asked, "In stamping this out of the Provinces, did you close any fountains?" He said, "We never thought it wise or necessary to close a single fountain." But there again you have the same condition, a national law by which compensation so abundant is given to every owner of a glandered horse that he does not try to conceal it or work it off among his fellows.

What I want to see is the most abundant supply of water furnished the horses of our cities and towns of Massachusetts that it is possible to furnish them under the most sanitary conditions. If it ever can be demonstrated that by the closing of every fountain you can wipe out glanders, I am willing to accept the statement, of course, but until many other things are done it seems to me to call fountain, which is the least of all the causes of the spread of glanders, the greatest, is to begin absolutely at the wrong end, or to spare at the spigot and to waste at the bung-hole.

VICE-PRESIDENT SULLIVAN. This is of much interest and importance to water-works people, particularly at this stage when we are talking so much about conservation. This type of watering station here is coming in to help us to save Massachusetts water. The old-fashioned watering trough on measurements taken could use from fifty to a thousand dollars' worth of water a year. It may be a small item in some places, but in places where they have to conserve the water it is of much importance.

MR. CARLETON E. DAVIS. *Mr. President*, — Philadelphia has between five hundred and six hundred public horse-watering-

troughs. Last May Dr. Marshall, state veterinarian, ordered them closed on account of the prevalence of glanders in the city. Up to May, about fifty cases of glanders had been reported.

A large number of the horse watering-troughs were closed without trouble. Some, however, remained open owing to complications arising from the fact that prepayment had been made on these fixtures.

Since the troughs have been closed, I am informed that the number of cases of glanders has decreased, though I cannot give actual figures.

A number of large team-owners have coöperated heartily in the effort to use individual pails as a substitute for the troughs. Other horse owners did not apparently coöperate heartily, and certain of the societies for the prevention of cruelty to animals were likewise antagonistic to the closing. For instance, one of the officers of one of the women's societies placed a spigot on the curb in front of her house and then put up a sign: "A pail for watering horses will be found in the bushes inside the yard." Of course she sympathized with the horses, but that common pail meant a condition practically identical with the public trough.

No effort has yet been made to control the common watering-trough in stables.

I am interested in noting the attachment for dogs in the sample watering-trough exhibited here to-day. In Philadelphia a great deal of sympathy has been expressed for the birds and dogs.

It seems probable from the sentiment which has been expressed here to-day, and the sentiment which has developed in Pennsylvania, that the common watering-trough is on the road to be permanently abolished.

Mr. Geo. F. Stebbins.* This is a subject in which I have been much interested for several years past, particularly as to what extent the watering of horses in this manner contributed to the transmission of the very contagious and always fatal disease known as glanders.

I am well aware of the differences of opinion on this subject by experts and the public expressions, *pro* and *con*, in connection with the closing of these troughs by the Commissioner of Animal

*Secretary Team Owners' Association, Boston.

Industry, and would present to you my reasons for being heartily in accord with this act.

For four years I have had 1 000 horses, belonging to members of this Association, under close inspection for glanders, every case being reported to me, and in this way have been able to collect some statistics that may be of interest. For the first three of the above years the average loss by glanders amongst these animals was between four and five per cent. of the total number per annum. Since the closing of the troughs, the loss by this disease figures less than one third of one per cent.

While there are many ways by which this disease may be communicated, my observations lead me to believe that the public watering-troughs have been the most fruitful, and the closing of them thoroughly warranted, as it entails no deprivation or hardship for man or beast.

MR. FRANK L. FULLER. I would like to ask about the individual bowls in horse-watering troughs, where I think each one is supplied by a separate supply and is running over constantly. Are they largely used?

DR. ROWLEY. I think the reference is to what is known as the Jenks fountain, which provides what is practically a bubbler fountain for the horse. The criticism upon that is that in cities and towns where you have a limited supply of water it is expensive. Here in Boston, where I imagine we have an abundant supply, — at least, the city has never objected to furnishing all the water we wanted for the fountains, — I think it would not cut very much figure. There is, however, invented by a gentleman in the South, and working at Tampa, Fla., a fountain on the same principle, a bubbler fountain, but the horse must step on the little iron platform as he comes up to this bowl to drink, when immediately the water gushes in and overflows the bowl, and as soon as he backs off the cock is closed and the flowing stops. That is working, and working very successfully. Then there is practically no waste of the water because the bowl gets a flush at the last minute before it is finally turned off and waits for the next horse.

MR. WALKER. Further answering the gentleman's question from the standpoint of the objection, the individual drinking cup as installed in some of the stations in Boston, as they were operated

prior to the time they were closed, did not eliminate the great danger that we appreciated in these public stations, namely, the shelf on which the horses diseased with glanders may deposit the germs, which in turn would be acquired by the horse that follows and rubs his nose, not on the water, but on the shelf that surrounds the water.

Dr. Rowley. If I might say one word more: Mr. Walker is scientifically, theoretically right, — that is all. But you probably cannot get into a street car that does not harbor a lot of germs of various diseases, — tuberculosis, pneumonia, typhoid fever, etc. You can't live in this world without breathing in bugs and germs constantly, and if you were in a particularly susceptible condition to-day and the germs get in their work, you are a goner. The other bugs inside of you may not be sufficient, in their state of health, to knock them out. In the same way, if a horse is in the condition to get glanders and gets his nose just where another horse blew his, not having a handkerchief, he probably will get into trouble. But you can go into a theater where there are any amount of germs, or nurse patients with various diseases, and yet not suffer harm if in good health.

Mr. Walker. I have no disposition, any more than Mr. Rowley, to monopolize all your time. He has said that I was theoretically right, and I appreciate the compliment. What we contend more forcibly than that we are theoretically right is that we are practically right, because we are getting results. We have the results in the nine months in Boston. We have the further evidence that we are practically right by the absence of an objection, as I have said before, by one team owner of importance. And we have not had an objection and I believe that that is evidence that we are practically right, because these same team owners are studying this situation. They have taken advice from veterinarians in whom they have confidence, and they have concluded, as a result of their interviews with their own veterinarians, as a result of their observation of their own horses, that we are practically right. Therefore, instead of condemning this move, they are commending it.

Mr. Percy R. Sanders. May I ask Mr. Merrill how he expects to take care of these fountains in the winter.

MR. MERRILL. So far, we think that we shall either close them in the winter or, if we can have authority from Mr. McInnes to install some of the very clever devices which he has arranged for his own use, we can allow them to remain running all winter without any danger of freezing. I am very glad you spoke of that, because I want to call your special attention to the fountains which the Boston water department has on exhibition here, and particularly to that clever arrangement of taking care of the flow of water through a small connection underneath this self-closing cock, which allows a small stream of water continually to run through the pipe, and prevents its freezing, and yet is not large enough to cause any great waste. I hope before you leave you will all take a look at that arrangement.

MR. WILLIAM C. LOUNSBURY. Mr. President, as I understand Mr. Walker, what he said applied wholly to glanders. I would like to ask him if there are other horse diseases that appear to be spread from the public watering-trough fountains.

MR. WALKER. I can answer that question purely on advice given me by those who in my opinion are the best authorities on such subjects in this and other states. They have invariably advised me that, so far as the spread of any disease was concerned other than glanders, the watering-trough was not the material cause, if of any importance, outside of its influence on horses relative to their digestive troubles. Dr. Gill, of New York, who is recognized as the leading veterinarian of that city, told me that there was a general protest in New York at the time the troughs were temporarily closed there, on the part of veterinarians, because of the marked diminution of colic cases. While I am making no particular claim in reference to such diminution, the advice I have received on the subject all tends to indicate that the absence of opportunity for horses that are heavily loaded and have been perhaps without water half a day to be driven to a trough where the water is running practically ice-cold and where they are allowed to stand and take into their systems much more than they should, or would if the driver realized how much it was until after he noticed the horse's bulging sides,—the elimination of such opportunities has materially decreased the cases of colic. But referring to other cases than glanders, I think it has not any importance.

MR. LOUNSBURY. I just wish to make this observation: We have at Superior a city veterinarian connected with the Health Department. The 1st of August the local water company was notified by the Health Department, on order from the city veterinarian, that the city watering-troughs should be closed. It seems in this case there was an epidemic of dysentery.

I think it might be of some interest to note that we have a new type of fountain in which there is a combination bubbling fountain for people which is continuously flowing, and an overflow from that which goes directly down into the horse trough; thus there is a continuous flow of water out from the trough.

MR. JOHN H. FLYNN. Mr. President, I would like to ask Dr. Rowley if there has not been an epidemic before this last one. Also if he has in mind that in the epizoötic of 1872 they did not shut the water off from the horse troughs.

DR. ROWLEY. I haven't the records back of 1909. There was a report circulated within this year that there had been a recent outbreak of glanders in London. I wrote at once to the secretary of the Association, and have his letter in my possession, to the effect that there had been no outbreak of glanders any more than the usual number of cases during a number of years. I think it is perfectly true that there are outbreaks of glanders, as of other diseases.

MR. WALKER. I feel that we could hardly say that there had been an epizoötic of glanders in Boston at any particular time because of the fact of record that for the ten years prior to the present year there had been a steady and rather more than gradual increase in the cases of glanders annually in that territory. In other words, it was growing on the authorities continually, — with some variations, to be sure, as Dr. Rowley has alluded to. At times there would be slight fluctuations in favor of the contention that might be made that the matter of the subject was under control.

Now, this matter is not settled, gentlemen. We are not here to say that we have the problem all solved, because it may be possible for any one who is inclined to doubt the efficiency and the advisability of adopting this measure of prevention to say next year that we have failed. But, so far, everything seems to

indicate that we are on the right track, and so long as we are I believe that you men are practical enough to say, with the team-owners and with the Department of Animal Industry, — let us stick to a policy that seems to be so far so creditable. As to the effect of the epizoötic that was so prevalent at the time of the Boston fire, I am of the opinion that that was in the nature of paralysis, — where the horses were attacked by some sort of paralysis. I don't know just what the character of the disease was, but I do not think it was in every sense a glanderous outbreak. I understand it was contagious. Naturally we would assume that the troughs, or any place where contagion should have been spread, should have been closed, but possibly the authorities were not as wise in their day and generation as those of to-day take credit for being.

WATER USES DIFFICULT TO CONTROL.

BY WILLIAM F. SULLIVAN, SUPERINTENDENT OF WATER WORKS, NASHUA, N. H.

[*Read September 10, 1914.*]

Wherever water is sold on the basis of flat rates or special rates, or where privileges are granted to some and not to others, even when it is not feasible that all could avail themselves of the privilege, it is difficult to closely control the use of water.

When it is incumbent upon water-works officials to control the use of unmetered water, it often appears that they require the assent of the governed. Municipal and town works are in much better position to govern water uses than are private companies. Municipalities and towns may make rules, regulations, and ordinances with almost the power of a statute, with authority to enforce the ordinance and penalize those who break or abuse the regulation.

If municipal water departments work in harmony with the other city departments, the governing and controlling of visible wastes and leaks are made less difficult. Particularly is this true when police departments report infraction of the rules.

The authority of private companies to enforce their rules is more limited than that of cities or towns. It is much simpler to govern when you are assisted by established laws, especially when they have been reasonably enforced from the beginning or for a long period. It is a well-known fact that most water works have at some time or other been lax in regulating certain uses of water. This often happens for economic reasons. Sometimes it pays not to enforce the rules. When the practice has been not to rigidly enforce the rules against what might be termed small or everyday wastes, and this laxity has made water takers careless and they have acquired the habit of using water uncontrolled or unregulated, it is no slight task to gain control.

Suddenly, for any of a number of reasons, it becomes necessary to restrict the uses of water in conformance to rules, and people who ordinarily have respect for law and constituted authority take the attitude that the water works is arbitrarily taking something from them, which they have always had, if not by law, then by custom.

The task, then, is to convince these people that a water works, like any other business, to be successful must be managed; that one of the cardinal rules of business is to use all alike; and that all customers should pay in proportion to what they use or get.

Former methods in the management of water works, still practiced in some places, have misled water takers to believe that because of former customers and because they have been paying a flat rate ungoverned, they are still entitled to use or waste water for any purpose they wish, even for power. These people will sometimes advance the hackneyed argument that "water is free, or ought to be free." They dismiss from their minds the value of water or service, and oftentimes exclaim: "The water is on a hill and only has to run down." Such statements as these are made regardless of whether the supply is on a hill or at sea level, or whether it is a conserved and protected supply or a filtered water. Some who give little thought to where the water comes from, or why it is ever ready at the faucets, give less thought to the fact that it costs money to produce good water.

In controlling the wasteful and profitless use of water, some water takers would lead you to believe that they do not want to pay their proportionate share, and frequently fall back upon the stock argument of rates, belittling their own supply and comparing the rates of their community with another with which they are familiar or have heard about, regardless of the facts, size, source, kind, or service of the works used in comparison. They usually neglect the elements of money invested in the plant or the cost of production. Usually the illustration is some municipal plant where rates are regulated by municipal authority and not by those who manage the works.

Municipal governments are short lived. While in control of affairs they seek the approval at times of citizens who do not give attention or study to municipal finances. Seldom do they con-

TYPES OF SINK FAUCETS AND NOZZLE TESTED.

sider in figuring costs of production all the elements chargeable to cost. The water works which does not figure its true cost of production usually has a misleading rate. The revenues of an established water works should cover operation and maintenance, the interest on the investment, depreciation, taxes, and in some cases a sum for a sinking fund to pay off bonded indebtedness. Quite often cities determining upon rates consider only the items of operation and maintenance. The tax levy or loans supply the deficit and money to pay for new construction, and sometimes even for renewals.

In order to meet all the elements of cost, it oftentimes becomes necessary to control and regulate the use of water. It is not to be supposed it was ever intended that these special uses or privileges should be allowed, and there is a growing understanding of what is legitimate use of water and what a reasonable and true rate should be.

It is not the scope of this paper to deal with major uses of water, such as fire services, etc., as this use at the present time is becoming well controlled, and there is a better understanding among water-works managers, underwriters, and the assured. Rather is it intended to treat of so-called minor uses difficult to control.

When the water rate for building purposes is a flat one, usually nominal, based on the size or kind of building, there is a waste due to the carelessness, sometimes willful, of the workmen. Much water for drinking purposes is allowed to run to waste. The workmen take a drink from the butt end of a hose or faucet, usually about a pint, the end of the hose is then dropped to the ground and left running. The discharge from the butt end of a hose with sillcock open one half is 9 gal. per minute. The water may be allowed to run to cool before taking a drink, and thus from 7 to 16 gal. per minute is wasted. Observations show that from 10 to 4 000 times as much water is wasted as drunk during the summer months on building construction.

For slaking lime and the tempering of mortar, the mixing of cement and concrete, on small jobs, the mason's helper or attendant, as a rule, does not shut off the water when he has enough for the needs at hand, but drops the butt end of the hose on the ground or sticks it into a cask already full of water, and the overflow runs

over the edge in a miniature waterfall. Quite often at quitting time the attendant goes home neglecting to shut off the water for the night.

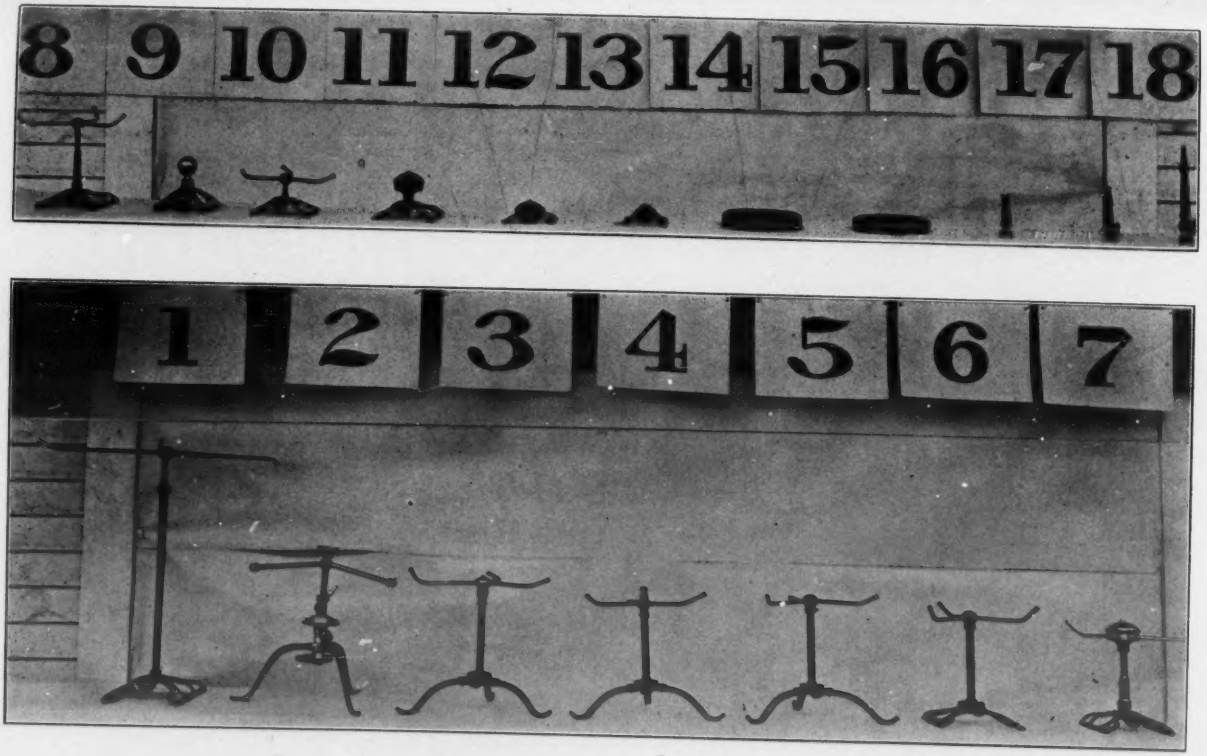
If the rate is a fixed sum per cask for lime or cement, averaging about 6 cents, the above-mentioned wastes are as frequent. Those who pay 6 cents per cask realize that the rate is excessive. Those who do the work know that it takes about 50 pails full, or 125 gal. per barrel of lime. This quantity of water, at a meter rate of 20 cents per thousand, would cost 2½ cents per barrel.

Equally so is it difficult to control and to account for water used if the rate is per thousand of brick laid, perch of stone laid, or yard of plaster spread. Efficient builders know this and are willing to have the water they use for building purposes metered. When the meters are not furnished by the water works, the contractor has a tested meter for such purposes. These men control a useless waste of water, and at the same time save money.

Water for building purposes is sometimes taken from adjoining premises before the owner of the new building has made application for water or before the water works has laid the new service. In cases where the neighboring premises are metered, there should be no charge on the part of the water works for the water used. The settlement should be between the owners of the premises. In adjusting the matter and making a proper charge, the owners of adjoining premises often have difficulty in controlling their tempers. The old resident believes the new resident at the beginning has overdone the neighborly act. It requires at times the services of an arbitrator or a police court judge to settle the matter.

When the adjoining premises has an unmetered supply, it sometimes requires explanations to show that the water works is entitled to compensation for the water used. The man with the service believes that he has a right to furnish water to his next-door neighbor, and both at times reason that the water is paid for once and that is sufficient. Both lose in their contention, as the charge is usually collectible of the owner of the new building.

City departments often assume the right to puddle trenches, flush streets and sewers at will. Flushing sewers is often done by plumbers and drain layers. A drain layer borrows several lengths of 2½-in. hose from the fire department, attaches it to a convenient



TYPES OF SPRAYS AND NOZZLES TESTED.

hydrant, places the nozzle into an opening in the drain or sewer and lets the water run. These men seldom know or little care that hydrants are set primarily for fire protection and are not designed to be opened and closed by unskilled hands at random. Such use of a hydrant in one day may be more severe on the working parts of a hydrant than twenty years of legitimate use. "Fire Stream Tables" show that with 150 ft. of average 2½-in. hose with 1⅛-in. nozzle and a hydrant pressure while stream is flowing of 50 lb. per sq. in., the discharge is 192 gal. per minute. Sometimes it takes hours and sometimes days to flush a sewer. Assuming an average of two hours, the use would be about 23 000 gal., for which at 20 cents per thousand the charge should be $4.60 plus something for the wear and tear. If charges were made for this kind of service, the persons doing the work would think it excessive.

In the same line of work as flushing sewers is flushing streets. The water works is called upon to sweep the streets and gutters and then follow the sweepings into the catch basins and often clean out the blocked sewers from these sweepings by flushing. This work should be controlled by a suitable charge and by the placing of suitable flush hydrants to be used in place of fire hydrants. The water used through 150 ft. of 2½-in. flush hose is about 11 000 gal. per hour, which at a 10-cent rate would cost $1.10 per hour per stream.

Where a water taker keeps a cow or cows and has an unmetered service, it is often convenient to have running water in the troughs for the cattle and to cool the milk. A faucet partially open runs about 10 gal. per minute, and running an hour in the morning and an hour at night uses at the 20-cent rate 24 cents worth of water per day.

A worthy special privilege is to allow the baby's night milk bottles to be kept cool and sweet from a running stream. The bottles are usually placed in a receptable and the water left running over them. Test on the flow from faucets shows that this cooling process will use water to the value of from 10 to 60 cents per night. Many a bottle of Budweiser is kept cool by use of a trickling stream, and the cooling costs the water works more than the value of the contents.

Another instance of waste is where the family goes away on a vacation and the man of the house stays at home. He sleeps at home, and if the service is on a dead end, he believes that in order to have a fresh drink of water during the night, he must turn on the faucet when he comes home and let it run all night. And it frequently happens that the water is permitted to run during the whole vacation period. This waste amounts to over 4 000 gal. in eight hours.

Many experiments have been made on the flow from orifices and nozzles, and it was thought it might interest some if the ordinary commercial sink faucets or plain bibbs were calibrated, as it were, and a few practical experiments made on discharges. Ten so-called $\frac{3}{4}$-in. sink faucets were selected. They were found to be approximately alike, but different in smoothness of bore and in the number of turns to open. The tests were made on the fractional parts of number of turns to open, that is, a $\frac{3}{4}$-in. plain bibb with an opening of $\frac{1}{16}$ of a turn flowed 2.1 gal. On full opening with $2\frac{1}{8}$ turns open, the flow was 24 gal. per minute. With a $\frac{1}{2}$-in. plain bibb and an opening of $\frac{1}{16}$ of a turn, the flow was 0.7 gal., and on $2\frac{1}{4}$ turns open the flow was 18 gal. per minute. The usual faucet opening that is commonly practiced by people who let the water run for these uncontrolled uses is from $\frac{1}{8}$ to $\frac{1}{4}$ turn. This waste is about 6.5 gal. per minute or 9 360 gal. in twenty-four hours. At 10 cents per thousand equals $0.93 per day.

On occasions, cooling pipes take the place of the thermos bottle and the family ice chest, and this source of waste can readily use from $1.00 to $3.00 worth of water per day.

Sometimes disciples of Izaak Walton, men who are thrifty enough to go out to the streams and gather thousands of shiners for bait, put shiner tanks into their cellar, shed, barn, or under the piazza. They do it in a manner to keep water-works officials from knowing about it, for they know that if they pay for the water to keep the shiners alive the industry is not a paying proposition. Knowing that a meter would place a tariff on the business which would kill it, they once in a while by-pass the meter. We were able to put a meter on a shiner tank with a so-called by-pass unknown to the owner, and found that he was using water to the value of $1.40 per day.

FIG. 1.
SPRAY BEING TESTED.

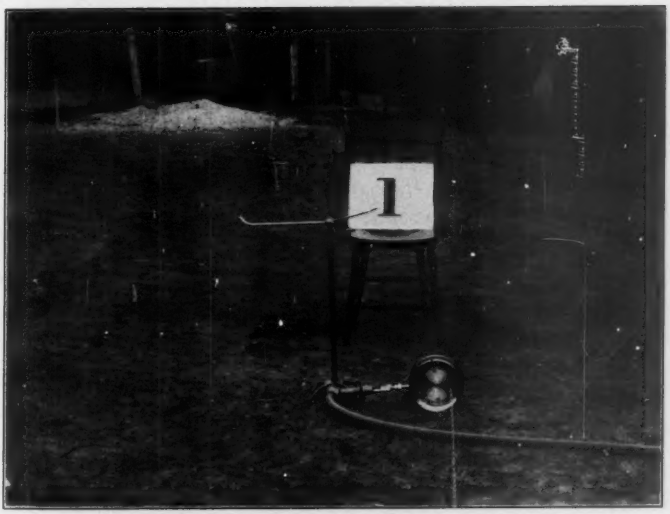


FIG. 2.
SPRAY READY FOR TEST.

Sometimes the sewing machine is run by a water motor, and the water works furnishes the family seamstress. The kitchen faucet and the degree of opening are the only guides as to what water is used. On installations of this kind, the only proper governor is a meter.

Nowadays the Monday-morning wash is done with a motorized wash tub. A water taker who paid a minimum charge of $6.00 per year objected to having a meter placed on a service which supplied the power to run a washing machine. This particular taker not only did the family washing, but took in washing. She was told that the water works was willing to furnish the water for the washing, but was not willing to do the washing. These machines are capable of using upwards of 1 000 gal. per hour.

The majority of hand-hose privileges are not abused. The persons paying for this privilege are reasonable. But there is a minority of takers in all unmetered communities who believe that in order to get value for what they pay on flat rates, they must use the hose extravagantly.

If the rule says that hand hose may be used on the premises between fixed hours of the day, the regulation is somewhat easier to enforce, especially where the police coöperate. But where the rule permits the use of hand hose a certain number of hours without specifying the exact hours, it is difficult in all cases to obtain close control. The right to use hose regardless of time limits is a common belief, and some people knowingly take advantage of the inability of a water works to have sufficient number of inspectors to keep a daily record of the hours of use. At night advantage is taken of the darkness and lack of supervision to use water on lawns and gardens indiscriminately. This abuse seems to be more prevalent with private companies than with municipal plants.

It has often been observed, when the temperature suddenly drops to freezing during the night, that the morning sun may be seen glistening on ice-covered lawns, shrubs, and plants. It is a common sight to see a fixed hose, nozzle, or spray running during a rain storm of many hours' duration.

The hose rate based on foot frontage is equally difficult to govern. In addition, it requires the checking up of frontages, while no regulation is provided for time. If hand hose only is used, it is reason-

able to suppose that this method is not so susceptible to abuse. It is a fact that some people are content to wet their lawns sufficiently to keep them in good condition, while others soak them and make them soggy.

In this era of back to the soil, when hundreds of families are practicing intensive farming and chicken raising, these pursuits require much water, and some of us realize that these minor uses of water are considerable and difficult to control.

In the rural districts supplied with water and paying but small interest returns on the cost of construction and a low minimum, means are sometimes taken to circumvent the water works by people who have large grounds or farms. The houses on these places often have the open drain pipe from the kitchen sink conveying water from the outlet through an open ditch, or arrange wooden troughs to carry the sink waste to a head ditch having laterals. During the dry period the sink faucet is kept open and the water allowed to run for long periods. Thus the water works furnishes a first-class irrigation system at low cost. One sink faucet can furnish by this means without aid of hose or pipes 25 000 gal. per day, or $5.00 worth.

Water takers will tie the hose nozzles to the back of a chair, fasten it through the handle of a garden fork, make a hitch to a wheel barrow, squeeze it into the fork of a tree, and sometimes the hose is coiled up into helix shape, the nozzle turned under and the stream or spray pointed in any direction desired.

If consumers' attention is called to these excessive uses, they will argue and interpret the rule which reads a certain number of hours per day for hand hose, that the rule means and permits a fixed spray or jet. "What difference is there between a fixed jet and a hand hose?" "Does the fixed jet, which is the same as the hand hose, use any more water?" Keeping up a rapid fire of questions, they will ask, "Do you expect me to stand or sit and hold a hand hose four hours per day, or do you want me to hire a boy for that work?" There have been cases where, rather than place a meter on the supply, they pay for the services of a boy or man to wet down, and thereby get the full privilege of the allotted hours. The reply is usually that because of the abuses of the time limit when fixed nozzles are used, it requires stricter regulations.

FIG. 1.
EXAMPLE OF NOZZLE FASTENED TO A STAKE.

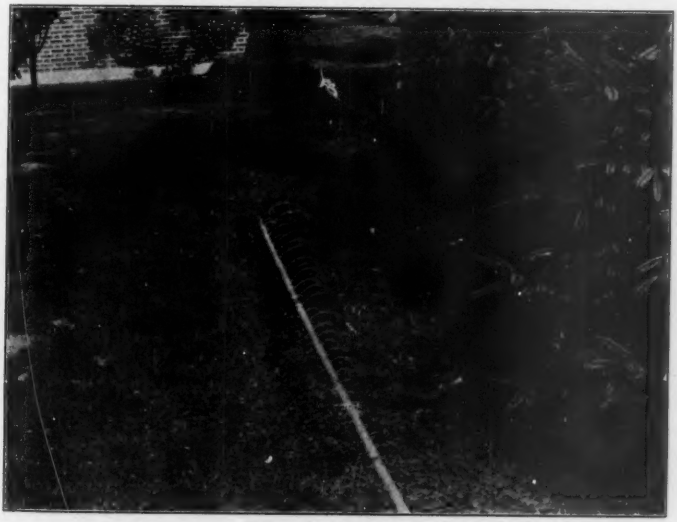


FIG. 2.
PERFORATED PIPE.

In states where public service commissions have been established, public utilities, unlike municipal plants, are not allowed to grant special privileges to cover individual cases. Private companies must not show any discrimination in rates or service. To carry out the orders of a public service commission and control the misuse of water by some, the water works is often obliged to meter fixed sprays and jets, and control by this means, the fairest and most equitable way, the use of water.

Instances are many where people permit hose streams to run night and day, week in and week out. In one case, a user paying four dollars a year for a hand-hose privilege with the right to use it four hours a day, fastened the nozzle to a block of wood and let the water run merrily on for weeks. The water works kept a record of the time and when the owner's attention was called to this misuse, she emphatically declared we were mistaken, notwithstanding that her neighbors complained that they were annoyed by the water running over the concrete walk and that the sizzling noise of the stream disturbed their slumbers. This particular misuse for twenty-four days wasted an estimated quantity of 691 200 gal.

Experiments were made on the discharge of garden hose to determine how much water a hose privilege of this kind used. Through 50 ft. of good quality $\frac{3}{4}$-in. rubber hose, at a pressure of 55 lb., and using a Boston nozzle, so-called, which has a spray attachment and a discharge orifice of 0.22 in. in diameter, the jet stream discharged 3.5 gal. per minute, while the spray attachment with a pressure of 45 lb. discharged 7 gal. per minute. The same nozzle with 25 lb. pressure discharged 2.5 gal. for the jet and 5 gal. for the spray.

The Fairy type of nozzle with an opening of .18 in. reversed the amount discharged by the jet and the spray. The jet discharged 7.5 gal. and the spray 2.5 gal. at 48 and 60 lb. pressure respectively. With a pressure of 25 lb. the jet discharged 5.5 gal. and the spray 2.0 gal. per minute.

The straight-tip type of nozzle discharged 7.5 gal. per minute at 47 lb. pressure.

The Boston type of garden hose nozzle with spray attachment discharges about 300 gal. per hour, or 7 200 gal. per day, which at

a 20-cent rate per thousand gallons, if metered, would amount to $1.44 per day.

The Fairy type spray nozzle with jet attachment uses 240 gal. per hour, or 5 760 gal. per day, or $1.15 worth of water at meter rates.

The ordinary straight-tip hose nozzle uses water to the value of $2.16 in twenty-four hours. The rate of 20 cents per thousand gallons is taken because it approximates the average cost of producing 1 000 gal. of water in the United States when all the factors are figured.

Another abuse of garden hose is by people who wantonly defraud the water works by removing the nozzle and letting the open butt run on to a brown or parched spot on the lawn. An open butt of a ¾-in. hose 50 ft. in length with a sillcock pressure of 55 lb. will discharge 16.5 gal. per minute, or 23 760 gal. per day, and should give a return to the water works of $4.75 per day.

In one instance, the discharge from such a butt was allowed to run on a brown patch with an area of a square yard for ninety-six hours. The original cost of this land was 10 cents per sq. ft., or 90 cents per sq. yd. The lawn cost about 6 cents per sq. ft. for loaming and grassing and the total cost per sq. yd. of lawn was $1.44, while the cost of the water used for four days should be for the square yard, $19.00, or $2.11 per sq. ft.

Open butts are also surreptitiously allowed to run under hedges and shrubbery. Long and short lengths of perforated pipes are concealed in and under the hedges and a hose or pipe connected. One of these perforated pipes uses about 15 gal. per minute, or in a day water to the value of $4.32, which is more than is received for a year's hose privilege.

The use of lawn and garden sprays, portable fountains, etc., has been given a great impetus in recent years in unmetered places. This increased use has come about principally by the low cost of sprinklers. The price of sprinklers ranges from 25 cents to $5.00, and some specially designed cost more. Test of the quantity of water used by sprinklers shows that some of these low-priced tin factory sprinklers use as much water and are as effective for the purposes designed as the more expensive ones.

In a city where the water company had an abundant supply

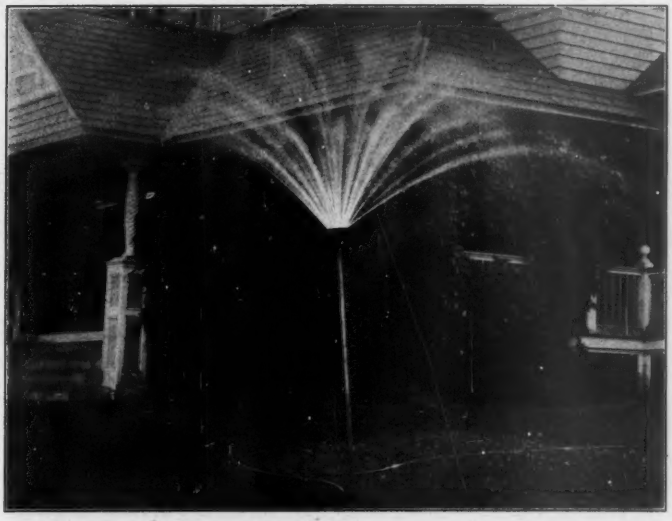


FIG. 1.
A FORM OF SPRAY USED.

FIG. 2.
A METHOD OF COILING HOSE.

and had generally permitted the water takers for years to make the city more beautiful by furnishing water to maintain the ever green appearance of their lawns and hedges, and this with little regulation or enforcement of the rule regarding sprays, there came a time when the abuse became excessive. Conservation of resources coupled with the present-day sentiment that special privileges and discrimination should cease, brought about a change in policy. This company like others realized that the granting of special privileges for what might be termed a civic betterment, or for reasons of expediency, were illogical, and adopted the following rule:

"Premises using water for ornamental fountains, portable fountains, garden or cooling sprays, or any automatic whirling or fixed jet or nozzle on garden hose, shall be metered."

After the publication and approval of this rule by the public service commission, inspections were made, and those breaking the rule were notified. The task was to enforce this rule with a minimum friction and ill-will on the part of the water takers. A campaign of education and explanation was carried on. The company fortified itself with many photographs showing the uses and misuses of sprays. There were many humorous phases of the picture-taking, persons not knowing the real object of the photographer posed beside the broken hose or running streams.

When it became known what the object of the picture-taking was, many takers held the hose instead of using the sprinkler. In some cases water takers had to be confronted with the photographic proof and sprinkler data to be convinced that they were getting something they were not paying for.

Fifteen sprinkling devices, such as are ordinarily for sale at hardware stores, were obtained and the discharges determined.

These tests were set up so that the experiments would be conducted as nearly like the ordinary use as possible. The table of discharges from sprinklers shows the flow per minute, per hour, and per day, by these devices, also the value of the water discharged for these periods of time.

If time permitted, there could be shown the waste and uses of leaky fixtures and the deliberately continuous use of water by both self-closing and non-self-closing water closets for flushing and

TABLE SHOWING DISCHARGES FROM LAWN SPRINKLERS, PENNICHUCK WATER WORKS, NASHUA, N. H. SEPTEMBER 1, 1914.

No.	Name.	Type.	Pressure		Diameter of Inlet. Inches.	No. of Outlets.	Diameter of Outlets. Inches.	Minutes Flowing.	Total Cubic Feet.	Total Gallons.	Gallons per Min.	Length ¾-in. Hose. Feet.	Spread of Spray. Diam. Ft.	Retail Price.	Gallons per Hour.	Gallons per Day.	Value of Water. 10c per Thousand Gallons.	
			At Sillcock	At Nozzle.													Per Hour.	Per Day.
1	E. S. Hotchkiss	Whirl	52	51	0.60	15	0.062	30	23	172.5	5.75	50	41	$2.50	345	8 280	$0.034	$0.828
,,	,, ,, ,,	,,	51	48	,,	,,	,,	,,	22	165.0	5.50	100	37	,,	330	7 920	0.033	0.792
,,	,, ,, ,,	,,	28	25	,,	,,	,,	,,	17	127.5	4.25	100	35	,,	255	6 120	0.025	0.612
,,	,, ,, ,,	,,	25	23	,,	,,	,,	,,	15	112.5	3.75	50	30	,,	225	5 400	0.022	0.540
2	Double Comet	Whirl and jet	57	51	0.62	1–3–49	0.142 0.080 0.036	15	13	97.5	6.5	50	56	5.00	390	9 360	0.039	0.936
,,	,, ,, ,,	,,	30	25	,,	,,	,,	,,	12	90.0	6.0	50	50	,,	360	8 640	0.036	0.864
,,	,, ,, ,,	,,	57	50	,,	,,	,,	,,	11	82.5	5.5	100	45	,,	330	7 920	0.033	0.792
,,	,, ,, ,,	,,	33	25	,,	,,	,,	,,	8	60.0	4.0	100	43	,,	240	5 760	0.024	0.576
3	Crescent	Whirl	48	25	0.62	15 15	0.062 0.072	15	20	150.0	10.0	100	40	.....	600	14 400	0.060	1.440
,,	,, ,,	,,	43	24	,,	,,	,,	,,	18	135.0	9.0	100	37	.....	540	12 960	0.054	1.296
,,	,, ,,	,,	49	34	,,	,,	,,	,,	19	142.5	9.5	50	40	.....	570	13 680	0.057	1.368
,,	,, ,,	,,	41	25	,,	,,	,,	,,	17	127.5	8.5	50	38	.....	510	12 240	0.051	1.224
4	No Name	Whirl	53	41	0.61	15	0.070	15	16	120.0	8.0	50	42	1.25	480	11 520	0.048	1.152
,,	,, ,, ,,	,,	36	25	,,	,,	,,	,,	13	97.5	6.5	50	38	,,	390	9 360	0.039	0.936
,,	,, ,, ,,	,,	54	42	,,	,,	,,	,,	14	105.0	7.0	100	41	,,	420	10 080	0.042	1.008
,,	,, ,, ,,	,,	33	25	,,	,,	,,	,,	10	75.0	5.0	100	39	,,	300	7 200	0.030	0.720
5	No Name	Whirl	55	42	0.60	15 2	0.062 0.055	15	15	112.5	7.5	100	44	.....	450	10 800	0.045	1.080
,,	,, ,, ,,	,,	35	25	,,	,,	,,	,,	11	82.5	5.5	100	41	.....	330	7 920	0.033	0.792
,,	,, ,, ,,	,,	53	47	,,	,,	,,	,,	15	112.5	7.5	50	44	.....	450	10 800	0.045	1.080
,,	,, ,, ,,	,,	34	25	,,	,,	,,	,,	11	82.5	5.5	50	41	.....	330	7 920	0.033	0.792
6	No Name	Whirl	56	49	0.60	11 2	0.061 0.055	15	13	97.5	6.5	50	46	.....	390	9 360	0.039	0.936
,,	,, ,, ,,	,,	30	25	,,	,,	,,	,,	8	60.0	4.0	50	44	.....	240	5 760	0.024	0.576
,,	,, ,, ,,	,,	55	44	,,	,,	,,	,,	12	90.0	6.0	100	42	.....	360	8 640	0.036	0.864
,,	,, ,, ,,	,,	35	25	,,	,,	,,	,,	8	60.0	4.0	100	39	.....	240	5 760	0.024	0.576

7	Hotchkiss	Whirl	50	30	0.41	{ 52 { 15	0.041 0.056	} 15	18	135.0	9.0	100	37	.....	540	12 960	0.054	1.296
,,	,,	,,	43	25	,,	,,	,,	,,	16	120.0	8.0	100	34	.....	480	11 520	0.048	1.152
,,	,,	,,	48	44	,,	,,	,,	,,	19	142.5	9.5	50	42	.....	570	13 680	0.057	1.368
,,	,,	,,	37	25	,,	,,	,,	,,	16	120.0	8.0	50	36	.....	480	11 520	0.048	1.152
8	Hotchkiss	Whirl	55	47	0.41	15	0.056	15	13	97.5	6.5	50	38	.....	390	9 360	0.039	0.936
,,	,,	,,	32	25	,,	,,	,,	,,	10	75.0	5.0	50	36	.....	300	7 200	0.030	0.720
,,	,,	,,	55	46	,,	,,	,,	,,	11	82.5	5,5	100	36	.....	330	7 920	0.033	0.792
,,	,,	,,	36	25	,,	,,	,,	,,	8	60.0	4.0	100	34	.....	240	5 760	0.024	0.576
9	No Name	Fixed	46	31	0.52	60	0.040	15	22	165.0	11.0	50	40	0.85	660	15 840	0.066	1.584
,,	,, ,,	,,	40	25	,,	,,	,,	,,	20	150.0	10.0	...	36	,,	600	14 400	0.060	1.440
,,	,, ,,	,,	47	27	,,	,,	,,	,,	21	157.5	10.5	100	38	,,	630	15 120	0.063	1.512
,,	,, ,,	,,	46	25	,,	,,	,,	,,	19	142.5	9.5	100	35	,,	570	13 680	0.057	1.368
10	Hotchkiss	Whirl	54	49	0.42	15	0.055	15	13	97.5	6.5	50	41	1.00	390	9 360	0.039	0.936
,,	,,	,,	30	25	,,	,,	,,	,,	9	67.5	4.5	50	36	,,	270	6 480	0.027	0.648
,,	,,	,,	56	48	,,	,,	,,	,,	12	90.0	6.0	100	38	,,	360	8 640	0.036	0.864
,,	,,	,,	36	25	,,	,,	,,	,,	8	60.0	4.0	100	35	,,	240	5 760	0.024	0.576
11	Hotchkiss	Fixed	54	45	0.42	50	0.032	15	16	120.0	8.0	50	38	1.00	480	11 520	0.048	1.152
,,	,,	,,	36	25	,,	,,	,,	,,	13	97.5	6.5	50	34	,,	390	9 360	0.039	0.936
,,	,,	,,	54	41	,,	,,	,,	,,	15	112.5	7.5	100	36	,,	450	10 800	0.045	1.080
,,	,,	,,	33	25	,,	,,	,,	,,	13	97.5	6.5	100	34	,,	390	9 360	0.039	0.936
12	No Name	Fixed	52	39	0.41	50	0.035	15	17	127.5	8.5	100	37	0.75	510	12 240	0.051	1.224
,,	,, ,,	,,	36	25	,,	,,	,,	,,	14	105.0	7.0	100	33	,,	420	10 080	0.042	1.008
,,	,, ,,	,,	52	41	,,	,,	,,	,,	17	127.5	8.5	50	39	,,	510	12 240	0.051	1.224
,,	,, ,,	,,	35	25	,,	,,	,,	,,	14	105.0	7.0	50	34	,,	420	10 080	0.042	1.008
13	Little Wonder	Fixed	54	49	0.40	1	0.32	15	12	90.0	6.0	50	36	0.25	360	8 640	0.036	0.864
,,	,, ,,	,,	30	25	,,	,,	,,	,,	8	60.0	4.0	50	28	,,	240	5 760	0.024	0.576
,,	,, ,,	,,	53	44	,,	,,	,,	,,	11	82.5	5.5	100	34	,,	330	7 920	0.033	0.792
,,	,, ,,	,,	31	25	,,	,,	,,	,,	8	60.0	4.0	100	27	,,	240	5 760	0.024	0.576
14	Niagara	Fixed	52	41	0.60	48	0.035	15	15	112.5	7.5	100	38	0.35	450	10 800	0.045	1.080
,,	,,	,,	36	25	,,	,,	,,	,,	13	97.5	6.5	100	35	,,	390	9 360	0.039	0.936
,,	,,	,,	53	44	,,	,,	,,	,,	15	112.5	7.5	50	38	,,	450	10 800	0.045	1.080
,,	,,	,,	32	25	,,	,,	,,	,,	13	97.5	6.5	50	36	,,	390	9 360	0.039	0.936
15	Hero	Fixed	55	46	0.62	56	0.038	15	15	112.5	7.5	50	36	0.50	450	10 800	0.045	1.080
,,	,,	,,	34	25	,,	,,	,,	,,	11	82.5	5.5	50	34	,,	330	7 920	0.033	0.792
,,	,,	,,	56	45	,,	,,	,,	,,	14	105.0	7.0	100	33	,,	420	10 080	0.042	1.008
,,	,,	,,	33	25	,,	,,	,,	,,	10	75.0	5.0	100	30	,,	300	7 200	0.030	0.720

TABLE SHOWING DISCHARGES FROM GARDEN HOSE NOZZLES, PENNICHUCK WATER WORKS, NASHUA, N. H. SEPTEMBER 1, 1914.

No.	Name.	Type.	Pressure.		Diameter of Inlet.	No. of Outlets.	Diameter of Outlets.	Minutes Flowing.	Total Cubic Feet.	Total Gallons.	Gallons per Minute.	Length ¾-in. Hose. Ft.	Horizontal Stream, no allowance for wind. Ft.	Retail Price.	Gallons per Hour.	Gallons per Day.	Value of Water. 10c per Thousand Gallons.	
			At Stillcock.	At Nozzle.													Per Hour.	Per Day.
16	Boston	Jet	60	55	0.563	1	0.22	15	7.0	52.5	3.5	50	45	$0.40	210	5 040	0.021	0.504
,,	,,	Spray	55	45	,,	,,	,,	,,	14.0	105.0	7.0	50	18	,,	420	10 080	0.042	1.008
,,	,,	Jet	30	25	,,	,,	,,	,,	5.0	37.5	2.5	50	37	,,	150	3 600	0.015	0.360
,,	,,	Spray	30	25	,,	,,	,,	,,	10.0	75.0	5.0	50	14	,,	300	7 200	0.030	0.720
,,	,,	Jet	60	55	,,	,,	,,	,,	7.0	52.5	3.5	100	45	,,	210	5 040	0.021	0.504
,,	,,	Spray	55	45	,,	,,	,,	,,	14.0	105.0	7.0	100	18	,,	420	10 080	0.042	1.008
,,	,,	Jet	30	25	,,	,,	,,	,,	5.0	37.5	2.5	100	37	,,	150	3 600	0.0150	0.360
,,	,,	Spray	32	25	,,	,,	,,	,,	11.0	82.5	5.5	100	18	,,	330	7 920	0.033	0.792
17	Fairy	Jet	57	48	0.600	1	0.18	15	15.0	112.5	7.5	50	47	0.50	450	10 800	0.045	1.080
,,	,,	Spray	65	60	,,	,,	,,	,,	5.0	37.5	2.5	50	10	,,	150	3 600	0.015	0.360
,,	,,	Jet	31	25	,,	,,	,,	,,	11.0	82.5	5.5	50	30	,,	330	7 920	0.033	0.792
,,	,,	Spray	30	25	,,	,,	,,	,,	4.0	30.0	2.0	50	6	,,	120	2 880	0.012	0.288
,,	,,	Jet	57	45	,,	,,	,,	,,	15.0	112.5	7.5	100	46	,,	450	10 800	0.045	1.080
,,	,,	Spray	61	59	,,	,,	,,	,,	6.0	45.0	3.0	100	10	,,	180	4 320	0.018	0.432
,,	,,	Jet	33	25	,,	,,	,,	,,	11.0	82.5	5.5	100	40	,,	330	7 920	0.033	0.792
,,	,,	Spray	28	25	,,	,,	,,	,,	4.0	30.0	2.0	100	6	,,	120	2 880	0.012	0.288
18	No Name	Jet	56	47	0.630	1	0.20	15	15.0	112.5	7.5	50	56	0.75	450	10 800	0.045	1.080
,,	,, ,,	Jet	31	25	,,	,,	,,	,,	11.0	82.5	5.5	50	39	,,	330	7 920	0.033	0.792
,,	,, ,,	Jet	56	45	,,	,,	,,	,,	15.0	112.5	7.5	100	54	.....	450	10 800	0.045	1.080
,,	,, ,,	Jet	33	25	,,	,,	,,	,,	11.0	82.5	5.5	100	46	.....	330	7 920	0.033	0.792

TABLE SHOWING FLOW OF SINK FAUCETS, PENNICHUCK WATER WORKS, NASHUA, N. H.
SEPTEMBER 1, 1914.

PLAIN BIBBS OR SINK FAUCETS.					AVERAGE PRESSURE.		GALLONS PER MINUTE FLOWING.												
Name.	Nominal Size of Faucet. Inches.	Diam. of Inlet. Inches.	Diam. of Outlet. Inches.	Total No. of Turns.	Static.	With Stream Flowing.	⅛ Turn.	⅙ Turn.	¼ Turn.	½ Turn.	¾ Turn.	1 Turn.	1¼ Turns.	1½ Turns.	1¾ Turns.	2 Turns.	2½ Turns.	2¾ Turns.	2½ Turns.
Mueller Standard	¼	⅛	⅛	2½	63	59	2.1	5.4	7.1	11.5	19.0	22.3	23.0	23.2	23.5	23.8	24.1	...	...
,, ,,	,,	,,	,,	,,	61	56	2.0	5.1	7.0	11.2	18.6	21.9	22.5	23.1	23.3	23.5	23.8	...	...
Mueller Extra	½	½	½	2½	57	53	0.7	3.9	9.7	12.6	15.3	17.7	18.1	18.2	18.2	18.3	18.4	18.6	19.0
,, ,,	,,	,,	,,	,,	58	54	0.8	4.0	10.3	12.8	15.5	18.6	18.2	18.2	18.2	18.6	18.6	18.7	19.0

to prevent freezing. There are so many and so varied small uses difficult to control that at this time it is the intention to mention only a few, and trust that a discussion will bring out others and by this means reveal to some of us uses, misuses, and abuses which we have not considered of much importance in the past.

The remedy for these abuses has been applied in those places which have adopted either universal metering or metering supplies which abuse the service privilege.

A further remedy which has been suggested to assist water-works managers to put their plants on a businesslike and practical basis would be the placing of municipal water works under the same supervision by state public service commissions as other public service corporations, for, after all is said, the municipal corporation has the same need of supervision as the private corporation. In the thickly settled portions of the country the end must come to continued extensions of water-collecting areas, and a broad and far-seeing control of wastes will do much to settle this most serious problem with which we are confronted.

FLOW OF OPEN BUTT, ¾-IN. GARDEN HOSE ATTACHED TO ¾-IN. SILLCOCK (PRESSURE AT SILLCOCK, 55 POUNDS), PENNICHUCK WATER WORKS, NASHUA, N. H. SEPTEMBER 1, 1914.

Sillcock Open in Turns.	Gallons per Minute.	Gallons per Hour.	Gallons per Day.	Value of Water.			
				10c per Thousand Gals.		20c per Thousand Gals.	
				Per Hour.	Per Day.	Per Hour.	Per Day.
¼	6.75	405	9 720	0.040	0.972	0.080	1.944
½	8.25	495	11 880	0.049	1.188	0.098	2.376
¾	9.00	540	12 960	0.054	1.296	0.108	2.592
1	13.50	810	19 440	0.081	1.944	0.162	3.888
1¼	15.00	900	21 600	0.090	2.160	0.180	4.320
1½	16.00	960	23 040	0.096	2.304	0.192	4.608
1¾	16.50	990	23 760	0.099	2.376	0.198	4.752
2	16.50	990	23 760	0.099	2.376	0.198	4.752
3	16.50	990	23 760	0.099	2.376	0.198	4.752
4	16.50	990	23 760	0.099	2.376	0.198	4.752
4¼	16.50	990	23 760	0.099	2.376	0.198	4.752

DISCUSSION.

MR. W. C. HAWLEY. Mr. President, I had a gentleman in my office, some time ago, objecting strenuously to a large bill for water supplied by meter. I explained the working of the meter and he was very decent about it and said he would investigate. He came back a few days later with a check for the amount of his bill and he explained, — "I went over to the house on Saturday afternoon and those blanked Hunkies had a keg of beer in the bathtub with the water running, getting it cool for Sunday."

I have some trouble on hand now that is a little different from anything Mr. Sullivan has mentioned. Perhaps some of the gentlemen here can help me toward its solution. A meter reader, some two or three months ago, reported a case where a meter read less at that time than it did three months before. An investigation showed that the seal on the meter had been broken, but the meter was on the pipe in the right position. We took the meter off and found decided evidence of wear on the end of the driving bar opposite to where it should have been, which seemed to indicate that that meter had been reversed and had then been put back in the right position. That house was one of a row of ten, I believe, and we took off three other meters in that row whose records seemed to indicate something peculiar in the consumption of the water. We found that those three showed the same indication of having been run backward as the first. The gentleman who owned those houses had several others, and we took off, I think, twelve meters supplying his houses. The other houses were vacant and we could not get the meters. All but one of those meters when examined showed evidence of the meters having been run backward although they were all in right when we took them off. Now I can't say positively that those meters had been reversed. We did not find them reversed, but there are the facts. That man has one son who is a plumber and one who is a lawyer, so you see what I am up against. I should like to know if any of the members have had similar experiences in the matter of evidence of reversed meters. We have only found a very few similar cases. We have been watching now for a couple of months, and we have had but two or three

meters come in that have indicated anything of that kind in that time. It has occurred to me that possibly if there was a pocket of air in the pipe when the water was shut off it might drive the disk back, and in that case might make a mark on the driving bar. Whether or not that is so, I do not know.

MR. FRANCIS T. KEMBLE. Mr. Hawley, I can give an answer to that. About five years ago I had an experience of that kind: I had five meters, all in houses owned by one man, that showed almost no registration. We watched them, and ultimately we found two of them reversed. The others were never reversed, but showed a low registration. After finding the first ones reversed, all these meters were sealed. We found that to beat us it was simply a matter of taking out the screws, removing the registering gear, and backing it up. We beat that by putting sealing wax over the screws, on which we use the Company seal. We have followed this practice with all our meters for the last few years, and have had no further trouble.

MR. JAMES A. MCMURRAY. I may say that in Boston we have experienced the same difficulty and we are quite satisfied that meters have been tampered with. At the present time there is a group of meters on premises owned by one individual in a certain section of Boston which have been giving us much annoyance. The owner of the properties has come into the office to complain about the size of the bills, despite the fact that some of the meters were set backwards. Since the visit of the owner we have sealed some of the meters, and upon a recent inspection we found that the meters had been reversed, showing that this was undoubtedly done after deliberation. I am satisfied that in some instances meters have been deliberately smashed when the registration was increasing.

Unless some statute is passed that will enable the cities and towns to stop this sort of thing, I do not think we can stop it. City and town ordinances appear to be of no avail. The present legislature has passed a statute placing the responsibility to a certain extent upon the owner, but the law department says that we must show that the owner or his agent was aware of the damage done to the meter.

Another point in connection with small registration: In a certain

part of Boston recently annexed, a trick was employed by a certain group of citizens who raised vegetables in small quantities. Instead of setting the meter backwards they have taken the screws off and taken the clock out, and, of course, while they were using water on the farm there was no registration. When they ceased using water the clock was dropped back into position and when the meter reader again visited the premises the registration, of course, was progressing. We suspected that something was wrong and after careful watch we found the above-mentioned condition. We are satisfied that it is impossible to have a meter register backwards unless the meter is actually so set.

There is another difficulty that we have met. If you examine a round dial clock very carefully you will see that you can readily detach the hands and adjust them to any reading you desire and at the same time have the hands continue to register as if nothing had been done to them. There were two or three houses in Boston where we suspected this condition on account of small registration. The repair department went to these buildings and took the clocks off, and upon careful scrutiny found the conditions as above mentioned. Of course, any reading could be had by any owner who employed that method to cheat the city. The only thing to do, as the gentleman has said, is to seal all meters in the section where trouble is expected. But in the absence of some effective law the sealing is of little avail if we cannot place the responsibility upon the individual.

Mr. Hawley. These meters were set a number of years ago before we used the sealing nuts on the inlet side of the meter. Some of them have been sealed since, but they were not all sealed. However, the screws on the register boxes were sealed. For some years past, we have been sealing all our meters with a twisted copper wire and lead seal, sealing both the inlet nut and also the screws on the registers. In the future, we shall seal both inlet and outlet nuts; but these meters, if tampered with, were reversed.

I had a case of that kind a couple of years ago, where a former employee of our water company, an Italian, that we might have supposed would be incapable of such a thing, reversed his meter without taking the seal off. He got all the slack he could in the

wire, loosened the nut one-eighth of a turn, backed the swivel out, and turned the meter around. He got a little too much to the good and his meter read less than on the previous reading. We studied the thing and finally decided how it had been done, and sent for him. I made the bill large enough to cover all the water he could have taken and added something to it and threatened him with prosecution, and he settled up. I have had two or three experiences of that kind. But if anything was done in this case I mentioned it was reversing the meter, and that is indicated by the wear on the other end of the driving bar of the intermediate gear.

MR. MCMURRAY. It just occurred to me that at the present time we are considering a case quite similar to the one Mr. Hawley has brought out. It may be that the sixth hand is stuck. Three months ago the register of the meter was 671 000. Two months since the meter reads 650 odd thousand. We didn't know what to do about that case, and after a preliminary inspection when everything appeared to be right we felt that the meter was probably stuck, and that it should be 750 000.

REPORT OF COMMITTEE ON YIELD OF DRAINAGE AREAS.

[*Read September 9, 1914.*]

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Croton River 514
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Appendix No. 2:
Explanation of Methods Employed in Computing Capacity Tables Nos. 11–23 525

To the New England Water Works Association:

Gentlemen, — On February 8, 1911, the Executive Committee of the Association, after considering a communication from Mr. C. E. Chandler, voted:

"That the President be and hereby is authorized to appoint a suitable committee to investigate the yields of New England watersheds and such other watersheds as the committee may deem desirable during the present dry period."

In accordance with this vote, a committee of nine was soon appointed by the President, and the number was subsequently increased to ten. The committee held its first meeting on March 8, 1911, and discussed at length the scope of the work of the committee and the nature of the inquiries which should be made in order to obtain the desired information.

It was soon found that the year 1911 was likely to be drier than the three preceding years, and that in order to make a satisfactory report the committee would necessarily have to wait for the records of that year. These records were not all received until January, 1913.

In western New England and in New York the drought was temporarily terminated by excessive rainfalls in the autumn of 1911, but in the central and eastern part of Massachusetts the low yield of the streams continued throughout 1912 and 1913, and also in 1914 to the time of making this report.

The remarkably dry period which has existed in central Massachusetts in the last six years is well shown by the records of the yield of the Wachusett drainage area, as follows:

TABLE 1.

YIELD OF WACHUSETT DRAINAGE AREA.

Year.	Yield in Gal. per Day per Sq. Mile.	Year.	Yield in Gal. per Day per Sq. Mile.
1897	1 253 000	1908	847 000
1898	1 551 000	1909	918 000
1899	1 051 000	1910	828 000
1900	1 264 000	1911	682 000
1901	1 507 000	1912	891 000
1902	1 248 000	1913	879 000
1903	1 285 000		
1904	1 025 000		
1905	926 000		
1906	1 043 000		
1907	1 180 000		
Averages,	1 212 000		841 000

It will be noted that the highest yield during the past six years is a little less than the lowest yield during the preceding eleven years, and that the average during the last six years is but little more than two thirds of the average during the preceding period. Owing to the construction and filling of the Wachusett Reservoir during the years 1904–1907, the per cent. of drainage area covered with water increased from an average of 3.1 in the first group of years to an average of 6.9 in the second group, and the consequent increase of evaporation accounts for a small part of the decrease in the yield of the later group of years.

GENERAL STATEMENT.

In general water-works practice, the yield of a drainage area — often called the "run-off" — is obtained by measuring the quantity of water drawn for consumption, adding to it the quantity running over the dam of the storage reservoir or otherwise wasted, and then making an addition or subtraction, as the case may be, for the amount of water added to or drawn from storage. The result is approximately the natural flow of the stream as it would be if the storage reservoir did not exist.

In the great majority of cases this approximation is sufficiently accurate for practical purposes, but when the best results are

desired there are other features which should be considered in order to make the records of yield obtained from certain drainage areas applicable to others.

Your committee has endeavored to make the correction which is as a rule the most important one, namely, that required to take account of the extent of the water surface upon a drainage area. Where a considerable proportion of an area consists of water surfaces, the evaporation causes the yield of the drainage area to be materially less, especially in the summer months, than if such water surfaces did not exist. Therefore, it is desirable, where accuracy is required, to divide the drainage area into land surfaces and water surfaces and consider the yield of each separately.

Swamps have water standing in them part of the year, and present damp surfaces much of the year, and may, therefore, be considered as intermediate between the upland from which the evaporation is least and the water surfaces from which the evaporation is greatest.

There are other corrections which it would be desirable to make but which cannot be made because the necessary data are lacking. For instance, in the case of large rivers like the Merrimack and Connecticut, it is not feasible to make corrections for the water drawn from or added to storage in the various reservoirs and mill ponds upon their drainage areas. Hence, the measured flow of such streams is not exactly the natural flow. The difference, however, is small except in the drier portions of the year, when the measured flow may be considerably more than the natural flow, and such streams cannot be used for deducing accurately the yield in dry times of drainage areas without storage.

Under ordinary conditions, when the correction is made for water added to or drawn from a storage reservoir, the correction covers only the visible storage and not the storage in the interstices of the ground around the reservoir. It is generally impracticable to include this feature in the computations. As a rule, the amount of such invisible storage is small in comparison with the visible storage, but it may be large enough to materially affect the deduced natural yield of a drainage area in dry months.

On a drainage area where proper correction is made for storage in the reservoirs under the control of the water authorities, there

are in some places other small reservoirs not under such control which are not included when making the corrections for storage.

In some instances, water is diverted from or into a drainage area in connection with systems of water supply and sewerage, and such diverted water is generally taken into account in preparing the records, but there is frequently some percolation or leakage past a dam, or through the natural barriers which retain a lake or reservoir, of which no account is taken.

The committee has endeavored to show in each case the extent to which the measured yield of the drainage areas has been corrected for these various reasons.

INFORMATION ASKED FOR.

In order to obtain the necessary information regarding the yield of drainage areas, a series of questions accompanied by blank forms, suggestions, and explanations was sent to water works superintendents and others who had records of the flow of streams in and near New England.

Sheet A was as follows:

SHEET A.

New England Water Works Association.
Committee on Yield of Drainage Areas.

*Data regarding Drainage Area of the*_____

Submitted by _____

(a) Name of stream or drainage area?

(b) Location of point where yield is measured?

(c) Area of drainage area, including water surfaces?

(d) Area of water surfaces of reservoirs of known size?

(e) Estimated area of water surfaces of other reservoirs, ponds, and streams?

(f) Estimated area of swamps —

Drained?
Undrained?
Total?

(g) To what extent is the measurement of run-off corrected for water drawn from or added to storage?

(h) In your judgment, is there any considerable amount of storage in the ground surrounding the reservoirs which becomes available as the water is drawn down? And can you give an estimate of the amount?

(i) Have you made any allowance for such invisible storage in your records of run-off?

(j) Is there any percolation, leakage, or diversion of water into or out of the drainage area which may materially affect the records of run-off?

(k) Character of drainage area? (As to slopes, kind of soil, to what extent forested, amount of storage in ground, etc.?)

(l) What is the run-off and rainfall for the years 1908, 1909, 1910, and 1911? (Please give these answers on the accompanying blank forms.)

(m) If you have earlier records of run-off from your drainage area lower or nearly as low as the records of 1908–1911, please give them on the blank forms.

(n) Method used in making measurements of run-off, and probable degree of accuracy.

(o) What kind of rain gages are used and how located? How is the snowfall measured and recorded?

(p) Note any changes in conditions of either drainage area or reservoirs that have taken place during the time that the yield of the drainage area has been measured, giving date of all changes.

(q) Give any additional information that may be of value in regard to the yield of this drainage basin.

Sheet B was a blank for recording the results for each year, as follows.

SHEET B.

New England Water Works Association — Committee on Yield of Drainage Areas.

Yield of the——————————For the Year——————Drainage Area,————Square Miles.

(1) Month.	YIELD OF DRAINAGE AREA. (2) Drawn for Consumption.	(3) Overflow and Waste.	(4) Gain (+) or Loss (−) of Storage.	(5) Total Yield of Drainage Area.	(6) Gain or Loss Due to Water Surfaces.	(7) Total Yield of Land Surface.	(8) Yield per Square Mile of Drainage Area. Gallons per Day.	(9) Yield per Square Mile of Drainage Area. Cubic Feet per Second.	(10) Yield per Square Mile of Land Surface. Gallons per Day.	(11) Yield per Square Mile of Land Surface. Cubic Feet per Second.	(12) Precipitation on Drainage Area. Inches.	(13) Precipitation Collected on Basis of Col. (5). Inches.	(14) Per Cent. of Precipitation Collected.
	MILLION GALLONS.												
Jan.													
Feb.													
March													
April													
May													
June													
July													
August													
Sept.													
Oct.													
Nov.													
Dec.													
The Year													

For explanation of column headings see Sheet D. Give daily or weekly yield during the driest one, two, or three months, where practicable, placing results on Sheet C.

Sheet C was arranged for recording the daily flows during the driest period of one, two, or three months, and is not reproduced.

Sheet D served as an explanation of Sheets B and C, as follows:

SHEET D.

New England Water Works Association.
Committee on Yield of Drainage Areas.

Suggestions and explanations regarding the preparation of run-off data (on Sheets B and C).

Object of Sheets B and C.

It is intended to have compiled on Sheets B and C data on the yield of a single drainage basin for one year, giving information as indicated in the various column headings as far as available, and as explained further below.

Explanation of Column Headings, Sheet B.

Column 1 requires no explanation.

Column 2 gives for each month the total amount of water in million gallons drawn from reservoir (or other source of supply) and used for consumption.

Column 3 gives for each month the total amount of water in million gallons overflowing at the reservoir or wasting in any other way. The sum of columns (2) and (3) represents the total amount of water actually leaving or passing by the reservoir each month.

Column 4 gives for each month the gain (+) or loss (—) of storage in million gallons corresponding to any rise or fall of water level and consequent change in quantity of water being held in any ponds or reservoirs on the stream.

Column 5 gives for each month, in million gallons, the total yield of the drainage area at the reservoir outlet corrected for any change in quantity of water stored. It is obtained by summing the results in Columns (2), (3), and (4), the latter being taken as + when there has been an increase in stored water during the month and as — when there has been a decrease in stored water. The results in Column (5) represent practically the water running into the reservoir (or reservoirs) as reduced by evaporation from reservoir surface and as increased by rainfall upon reservoir surface. If there is no storage in the drainage basin, Column (4) would be left blank and Column (5) would be simply the sum of Columns (2) and (3).

Column 6 gives for each month, in million gallons, the gain or loss due to the difference between the rainfall upon and the evaporation from the water surfaces. In determining the gain or loss, take into account the diminished area of water surfaces as the reservoirs are drawn down; and to provide for the excess of evaporation from the swamps over the evaporation from the upland,

include with the water surfaces 30 per cent.of the area of drained swamps and 40 per cent. of the area of the undrained swamps.

For the amount of evaporation (unless you have data more applicable to the situation), use the mean monthly evaporation as given by Mr. Desmond FitzGerald in his paper on Rainfall, Flow of Streams, and Storage, Trans. of Amer. Soc. of Civil Engrs., Sept., 1892, p. 275, as given below.

Each inch of difference between the evaporation and the rainfall is equivalent to 27 154 gallons per acre and to 17 379 000 gallons per square mile.

EVAPORATION.

Month.	Inches.
January	0.96
February	1.05
March	1.70
April	2.97
May	4.46
June	5.54
July	5.98
August	5.50
September	4.12
October	3.16
November	2.25
December	1.51
	39.20

Column 7 gives for each month, in million gallons, the total yield of land surface alone in the drainage area obtained by subtracting (or adding) the results in Column (6) to those in Column (5). Column (6) will be subtractive when evaporation from reservoir surface is **less** than rainfall upon it; Column (6) will be additive when evaporation from reservoir surface **exceeds** rainfall. Column (7) thus represents the yield of **land surface alone.**

Columns 8 and 9 give for each month the yield per square mile of the drainage area in gallons per day and cubic feet per second, computed from the results in Column (5) as a basis. Columns (8) and (9) therefore represent **unit** yield as regards the entire drainage area, including water surface.

Columns 10 and 11 give for each month values of unit yield similar to those in Columns (8) and (9) but based upon the results in Column (7). Columns (10) and (11) therefore represent unit run-off from the drainage area as regards land surface **only.**

If data are not available to compute Columns (6) and (7), Columns (10) and (11) will of course be omitted.

Column 12 gives, for each month, the precipitation on the drainage area, in inches.

The location of the rain gage stations that are used in the determination of precipitation on the drainage area should be noted on Sheet A under (o).

What is desired in Column (12) is the **average** precipitation over the whole drainage basin, and if the figures of precipitation are not believed to be truly representative of the basin as a whole, this should be stated on Sheet A, under (o), and any additional information given that will be helpful in estimating the true **average** precipitation.

Column 13 gives for each month the precipitation collected or the run-off from the drainage basin expressed in inches depth over the entire basin, based on the results given in Column (5).

Column 14 is obtained by dividing Column (13) by Column (12) and multiplying by 100.

Partially Complete Data.

In many cases it will not be possible with information at hand to fill in all the columns on Sheet B. In such cases, information should be given as far as available. The committee will be glad to complete any sheets where this is simply a matter of computation, but should be supplied with all necessary base data.

Additional Data to be placed on Sheet C.

In addition to the results called for by Sheet B, it is desired by the committee to obtain daily or weekly records of yield during the very dry period. These should be given for the driest one, two, or three months, and can be placed upon Sheet C, with appropriate notes.

In answer to the inquiries made, returns were received of the yields of twenty-two drainage areas, as follows:

Drainage Area.	Period Covered.
Maine.	
Sebago Lake	1908–1911
New Hampshire.	
Connecticut River at Orford, N. H.	1908–1911
Massachusetts.	
Connecticut River at Sunderland, Mass.	1908–1911
Deerfield River at Shelburne Falls, Mass.	1908–1911
Merrimack River at Lawrence, Mass.	1908–Mar., 1912, inc.
Cambridge Water Works, Stony Brook	1908–Feb., 1912, inc.
Holyoke Water Works, Manhan River	1899, 1900, 1908–1911
Metropolitan Water Works:	
Wachusett Reservoir	1908–1914
Sudbury River	1879–1884, inc., 1908–Feb., 1912, inc.
Lake Cochituate	1908–1912
Springfield Water Works:	
Borden Brook	1910–Oct., 1912, inc.
Westfield Little River	1908–1911

Drainage Area.	Period Covered.
Westfield Water Works, Tillotson Brook	1908–1911
Worcester Water Works, Tatnuck Brook	1908–Feb., 1912, inc.
Rhode Island.	
Pawtucket Water Works, Abbott Run	1908–1912
Connecticut.	
Hartford Water Works, Hartford Reservoirs	June, 1909–1912
Norwich Water Works, Fairview and Meadow Brooks	1910–1912
Waterbury Water Works, West Branch of Naugatuck River	1908–1912
New York.	
New York Water Works:	
Croton River	June, 1879–1883, 1908–1913
Esopus Creek	1908–1913
Rondout Creek	1908–1911
Schoharie Creek	1908–1911

YIELD FROM WATER SURFACES.

As already indicated, the actual measurements of the yield of a drainage area necessarily cover both land and water surfaces. It is desirable to deduce the yield of the land surface. In order to do this, it is necessary to determine first the yield of the water surfaces. Such a yield in any given period is the difference between the precipitation on the water surfaces and the evaporation therefrom. It is sometimes a plus quantity and sometimes a minus quantity, depending upon whether the precipitation is greater or less than the evaporation.

The amount of precipitation is easily determined from some neighboring gage, but the actual determination of evaporation is a very difficult matter, so that as a substitute for the actually measured evaporation the results of careful experiments made elsewhere are generally used. This can be done without serious error, because the evaporation for a given month in different years does not vary very much.

The committee has used, for the purpose of determining the yield of water surfaces, the results of the careful and extended experiments upon evaporation made by Mr. Desmond FitzGerald, member of the Association, given in his paper on "Rainfall, Flow of Streams, and Storage," in Transactions of American Society of Civil Engineers, September, 1892, page 275, as follows:

TABLE 2.

EVAPORATION FROM WATER SURFACES.

Month.	Average Temperature of Water in Degrees Fahrenheit.	Evaporation in Inches.
January	32.8	0.96
February	32.4	1.05
March	36.4	1.70
April	46.5	2.97
May	58.6	4.46
June	67.9	5.54
July	72.3	5.98
August	71.3	5.50
September	65.6	4.12
October	53.6	3.16
November	42.8	2.25
December	34.3	1.51
		39.20

These experiments were made at Chestnut Hill Reservoir,* Boston.

Since evaporation depends largely upon the temperature of the water, there would be less evaporation where the water is cooler and more where it is warmer than at Chestnut Hill Reservoir.

The above table and other evaporation experiments indicate that each nine degrees, Fahrenheit, of change in water temperature corresponds to about one inch per month of change in the amount of evaporation. A smaller evaporation than that given by the above table was used in determining the yield of water surfaces on the Sebago Lake drainage area.

In computing the yield of water surfaces in gallons per day by the method indicated, allowance was made in practically all cases for the reduction in the area of water surfaces as the reservoirs were drawn down.

* The rate of evaporation has been measured in Maine by the United States Geological Survey in coöperation with private parties, at four places, during a part or the whole of the period from July 1, 1905, to November 7, 1908, and the results are given in Water Supply Paper No. 279, entitled, "Water Resources of the Penobscot River Basin, Maine." The annual evaporation, as deduced from these measurements, is substantially 26 inches.

YIELD FROM LAND SURFACES.

In some cases, as, for instance, the drainage areas of the Manhan River and Tillotson Brook, and the drainage areas in the Catskill Mountains, the water surfaces were practically negligible, so that the flow from the whole drainage area is practically identical with the flow from the land surfaces. In other cases, the yield of the water surfaces was computed and subtracted from the total yield for each month, the remainder being the yield from land surfaces, and this divided by the number of square miles of land surface gave as a quotient the yield per square mile of land surface. The area of the land surface increased slightly as reservoirs were drawn down, but no account has been taken of this increase, the area of land surface used for a divisor being that corresponding to high water in the reservoirs.

SWAMPS.

As already indicated, the yield of swamps is less than that from land surfaces, and probably more than that from water surfaces. No actual measurements of the yields from such areas have been made, but a study of the subject in some detail indicated that a correction might be made for the effect of swamps by classing 40 per cent. of the area of an undrained swamp with the water surfaces and 60 per cent. with the land surfaces. In the case of swamps which have been carefully drained to improve the quality of the water supplied to a reservoir, the percentages assumed are, respectively, 30 and 70.

COMPILATION OF RETURNS.

After the various returns had been received, they were put in form for presentation to the Association by rewriting to make them more concise and uniform, by adding additional information to the descriptive matter, and by including the results of certain computations required to make the tables of yield more complete.

The amended descriptions and tables of yield are given in Appendix No. 1. The tables as presented therein are in somewhat different form from those received by the committee in answer to its inquiries for information. Certain columns in the original tables which have little practical value for purposes of record have

been omitted, to make room for other columns containing computed results which are more instructive.

A preliminary examination of the different records made it very evident that there were large differences in the yield per square mile of different drainage areas, even after corrections had been made for variation in the extent of the water surfaces. In order that these differences might be shown as clearly as practicable, a table was prepared for each drainage area, made up in the following manner: A search was made through the records to ascertain for each drainage area the yield per square mile of land surface in the driest month; then in the driest two consecutive months, and so on, until a table was completed which gave the average yield per square mile of each drainage area for all periods from one month to the full number covered by the record.

In making this table, no account was made of the different lengths of the different months of the year, as that would have involved much computation and seemed to be an unnecessary refinement; that is, the yield in gallons per day per square mile for a 30- and a 31-day month was averaged directly, instead of giving greater weight to the yield during the longer month.

The following — a part of the Wachusett table — is given as a specimen:

TABLE 3.

WACHUSETT DRAINAGE AREA.

Driest Consecutive Months on Basis of Yield from Land Surface.

Number of Consecutive Months.	Driest Consecutive Months.	Average Yield in Gallons per Day per Square Mile.
1	Oct., 1910	158 000
2	Sept.–Oct., 1910	190 000
3	July–Sept., 1913	205 000
4	July–Oct., 1910	240 000
5	July–Nov., 1910	251 000
6	July–Dec., 1910	274 000
7	July, 1908–Jan., 1909	334 000
8	June, 1908–Jan., 1909	376 000
9	June, 1910–Feb., 1911	442 000
10	May, 1910–Feb., 1911	477 000
11	Apr., 1910–Feb., 1911	536 000
12	Sept., 1910–Aug., 1911	582 000
13	Sept., 1910–Sept., 1911	557 000
14	Aug., 1910–Sept., 1911	538 000
15	July, 1910–Sept., 1911	521 000
16	July, 1910–Oct., 1911	532 000
17	June, 1910–Oct., 1911	556 000
18	May, 1910–Oct., 1911	570 000

Having completed such tables, the results were plotted on diagrams so that the differences might be shown graphically. These diagrams are reproduced herewith. (See Plates IX, X, and XI.)

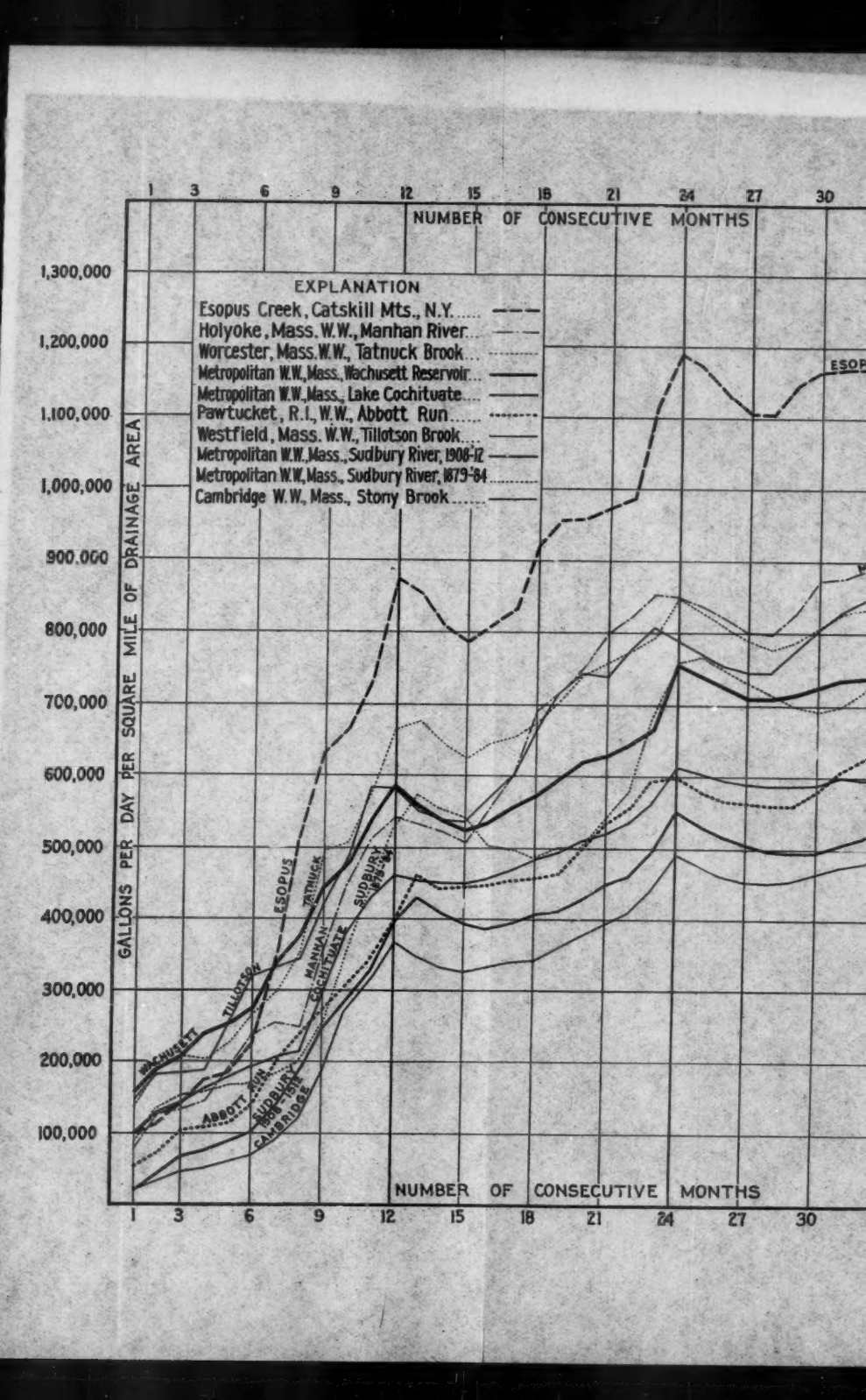
The diagrams were constructed in the following manner: At the bottom is shown the number of consecutive months, from 1 to 60. The vertical scale shown on the left-hand side represents the yield in gallons per day per square mile of drainage area. The lines on the diagram, each representing a drainage area, were plotted from the tables already described, and they show the mean yield of the drainage area for the number of consecutive months of minimum yield shown at the bottom of the diagram. For instance, if it were desired to know the yield of the various drainage areas on Plate IX for the driest six consecutive months during the dry period under consideration, one would look first for the six months period at the bottom of the diagram, and then could read directly from the vertical scale that the yields were as follows:

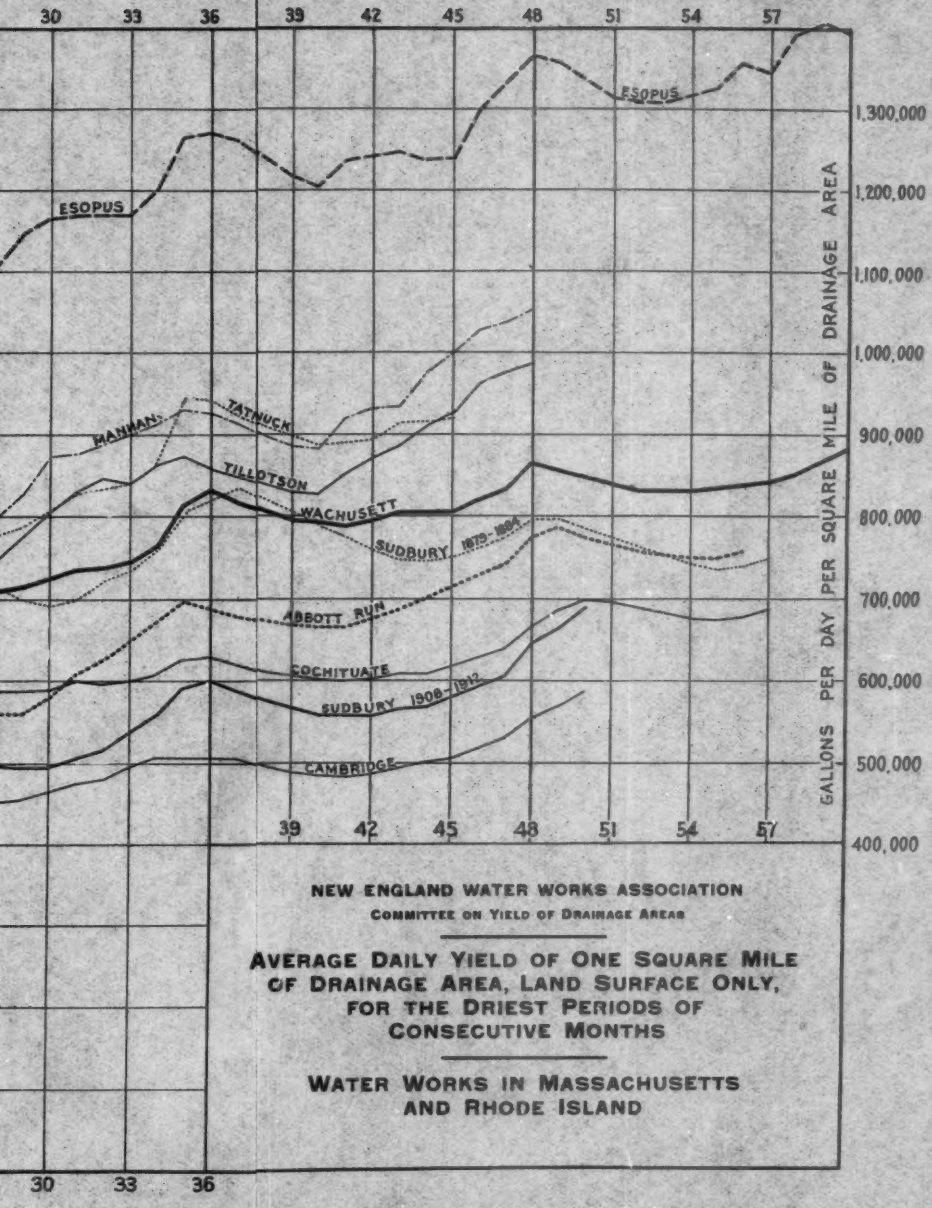
Drainage Area.	Average Yield per Square Mile. Gallons per Day.
Cambridge	68 000
Sudbury, 1908–1912	100 000
Abbott Run	140 000
Sudbury, 1879–1884	169 000
Cochituate	192 000
Esopus Creek	225 000
Manhan River	237 000
Tatnuck Brook	265 000
Wachusett	274 000
Tillotson Brook	319 000

For a period of thirty-two months, the corresponding figures for the same drainage areas are as follows:

Drainage Area.	Average Yield per Square Mile. Gallons per Day.
Cambridge	478 000
Sudbury, 1908–1912	511 000
Cochituate	595 000
Abbott Run	624 000
Sudbury, 1879–1884	721 000
Wachusett	737 000
Tatnuck Brook	832 000
Tillotson Brook	846 000
Manhan River	898 000
Esopus Creek	1 165 000

These diagrams, and the above figures taken from them, show that there is a very radical difference in the yield of different


NUMBER OF CONSECUTIVE MONTHS
1 3 6 9 12 15 18 21 24 27 30
EXPLANATION
Esopus Creek, Catskill Mts., N.Y.
Holyoke, Mass. W.W., Manhan River
Worcester, Mass. W.W., Tatnuck Brook
Metropolitan W.W., Mass., Wachusett Reservoir
Metropolitan W.W., Mass., Lake Cochituate
Pawtucket, R.I., W.W., Abbott Run
Westfield, Mass. W.W., Tillotson Brook
Metropolitan W.W., Mass., Sudbury River, 1908-12
Metropolitan W.W., Mass., Sudbury River, 1879-84
Cambridge W.W., Mass., Stony Brook
GALLONS PER DAY PER SQUARE MILE OF DRAINAGE AREA
1,300,000
1,200,000
1,100,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
ESOPUS
TATNUCK
SUDBURY 1879-84
MANHAN
COCHITUATE
TILLOTSON
WACHUSETT
ABBOTT RUN
SUDBURY 1908-12
CAMBRIDGE
NUMBER OF CONSECUTIVE MONTHS
1 3 6 9 12 15 18 21 24 27 30

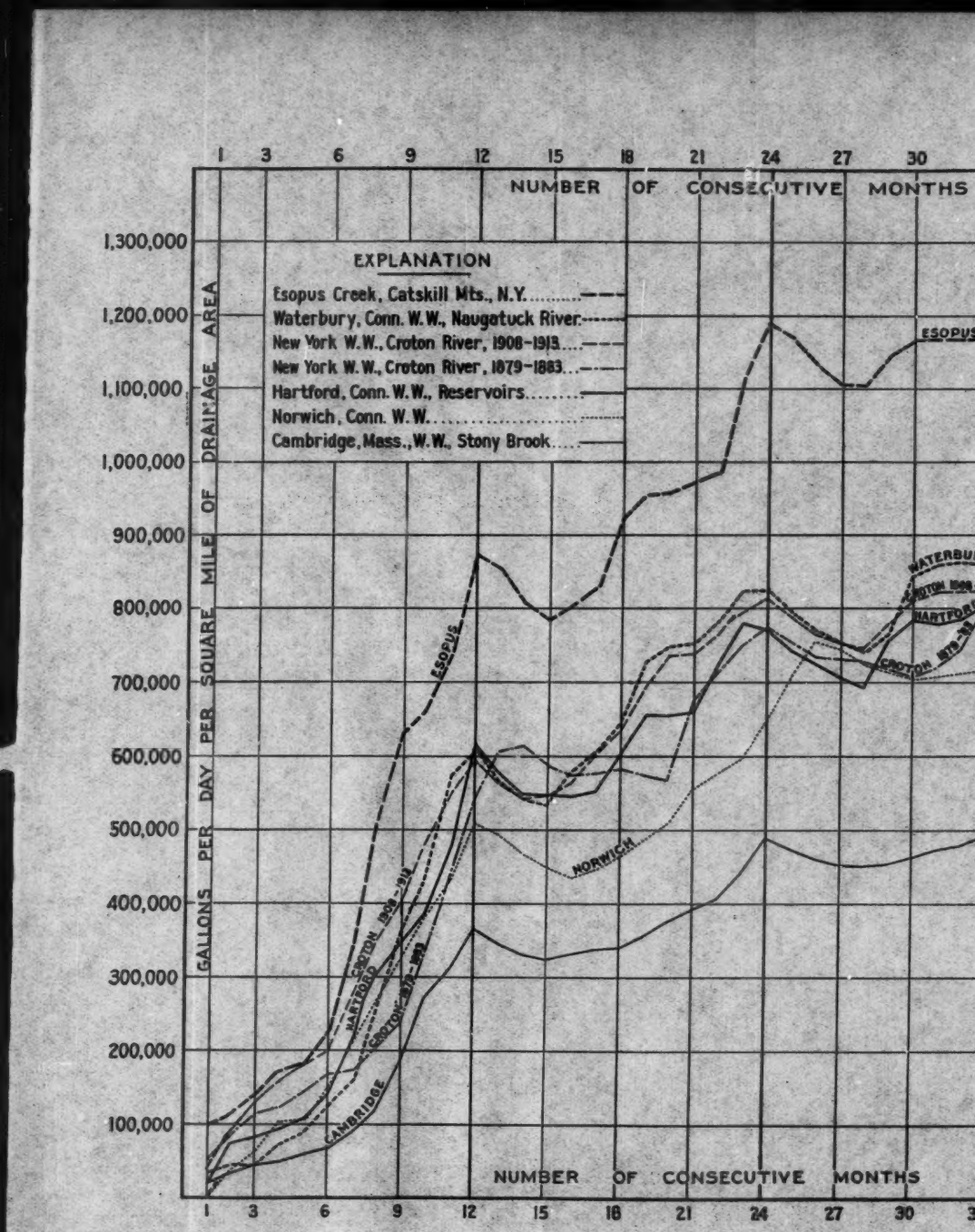


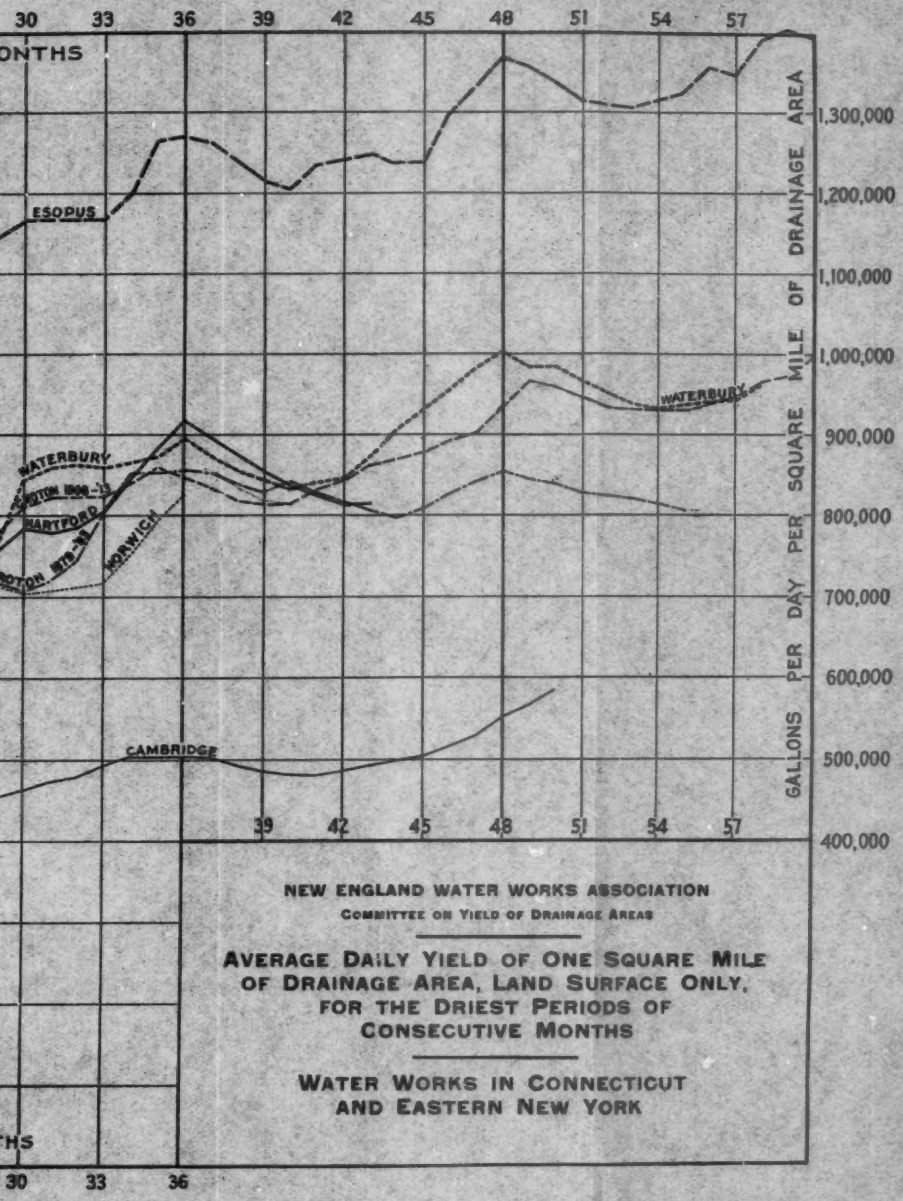
NEW ENGLAND WATER WORKS ASSOCIATION

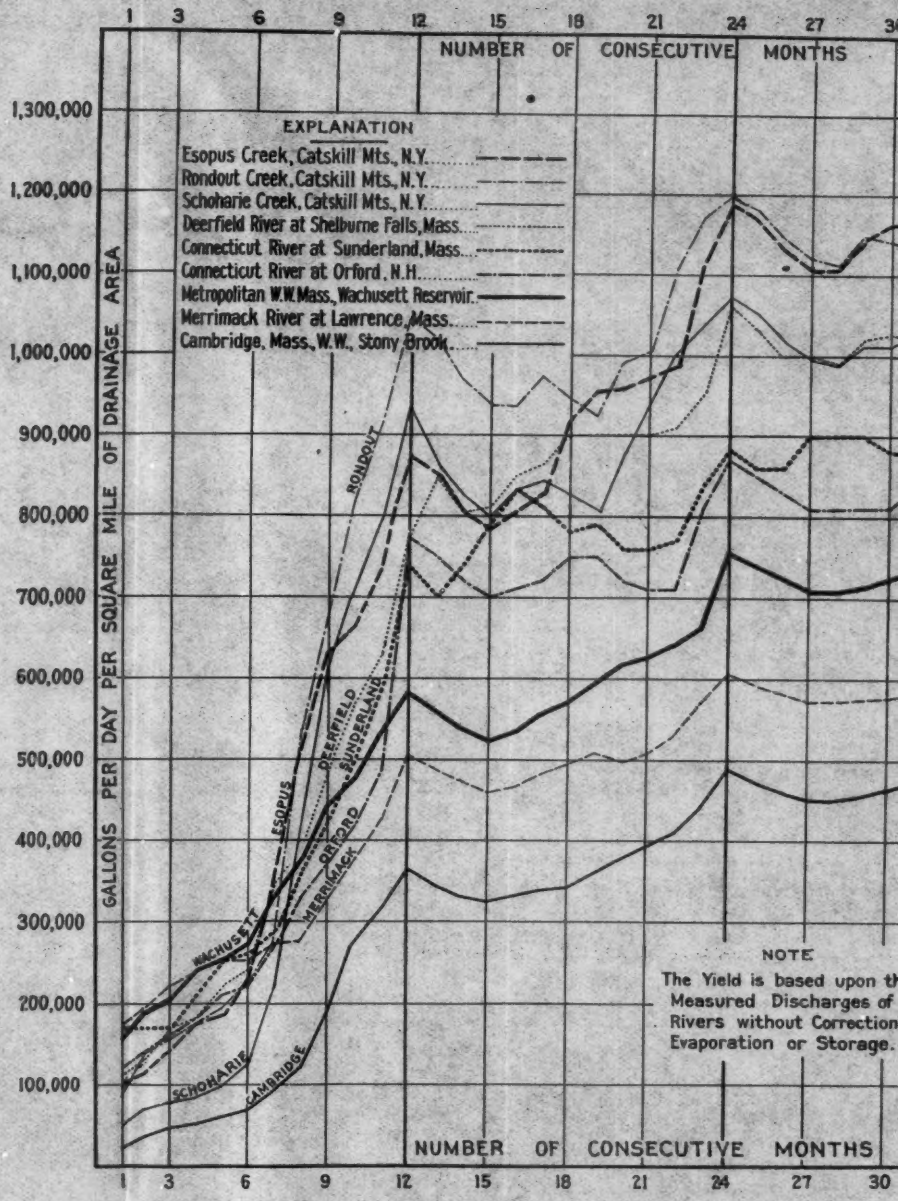
COMMITTEE ON YIELD OF DRAINAGE AREAS

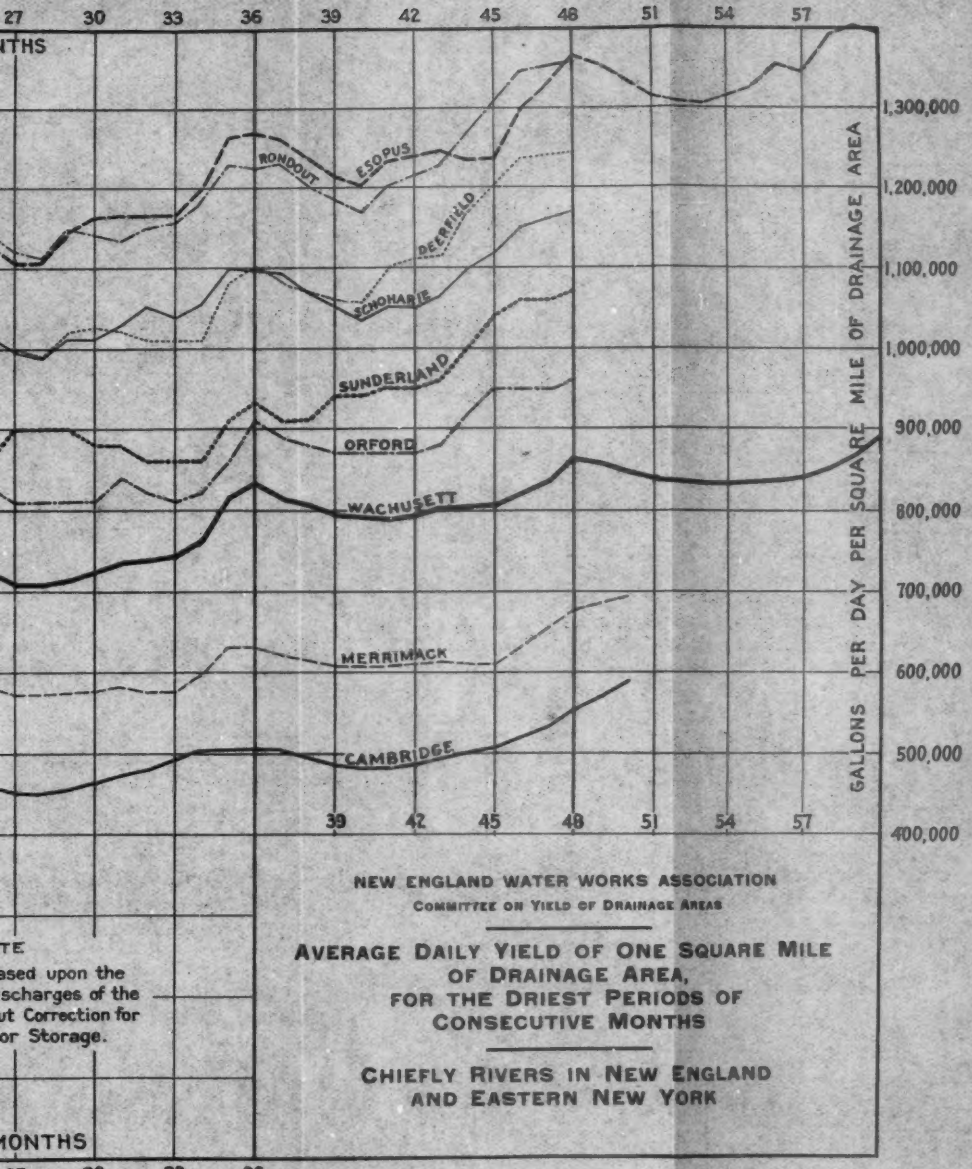
AVERAGE DAILY YIELD OF ONE SQUARE MILE OF DRAINAGE AREA, LAND SURFACE ONLY, FOR THE DRIEST PERIODS OF CONSECUTIVE MONTHS

WATER WORKS IN MASSACHUSETTS AND RHODE ISLAND


NUMBER OF CONSECUTIVE MONTHS
1 3 6 9 12 15 18 21 24 27 30
EXPLANATION
Esopus Creek, Catskill Mts., N.Y.
Waterbury, Conn. W.W., Naugatuck River
New York W.W., Croton River, 1908-1913
New York W.W., Croton River, 1879-1883
Hartford, Conn. W.W., Reservoirs
Norwich, Conn. W.W.
Cambridge, Mass., W.W., Stony Brook
GALLONS PER DAY PER SQUARE MILE OF DRAINAGE AREA
1,300,000
1,200,000
1,100,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
ESOPUS
NORWICH
CAMBRIDGE
HARTFORD
CROTON 1908-1913
CROTON 1879-1883
WATERBURY
HARTFORD
CROTON 1879-1883
NUMBER OF CONSECUTIVE MONTHS
1 3 6 9 12 15 18 21 24 27 30


30
33
36
39
42
45
48
51
54
57
ONTHS
ESOPUS
WATERBURY
HARTFORD
NORWICH
CAMBRIDGE
WATERBURY
GALLONS PER DAY PER SQUARE MILE OF DRAINAGE AREA
1,300,000
1,200,000
1,100,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
NEW ENGLAND WATER WORKS ASSOCIATION
COMMITTEE ON YIELD OF DRAINAGE AREAS
AVERAGE DAILY YIELD OF ONE SQUARE MILE OF DRAINAGE AREA, LAND SURFACE ONLY, FOR THE DRIEST PERIODS OF CONSECUTIVE MONTHS
WATER WORKS IN CONNECTICUT AND EASTERN NEW YORK


NUMBER OF CONSECUTIVE MONTHS
1 3 6 9 12 15 18 21 24 27 30
GALLONS PER DAY PER SQUARE MILE OF DRAINAGE AREA
1,300,000
1,200,000
1,100,000
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
EXPLANATION
Esopus Creek, Catskill Mts., N.Y.
Rondout Creek, Catskill Mts., N.Y.
Schoharie Creek, Catskill Mts., N.Y.
Deerfield River at Shelburne Falls, Mass.
Connecticut River at Sunderland, Mass.
Connecticut River at Orford, N.H.
Metropolitan W.W. Mass., Wachusett Reservoir.
Merrimack River at Lawrence, Mass.
Cambridge, Mass., W.W., Stony Brook
ROUNDOUT
DEERFIELD
SUNDERLAND
ESOPUS
ORFORD
MERRIMACK
WACHUSETT
SCHOHARIE
CAMBRIDGE
NOTE
The Yield is based upon th
Measured Discharges of
Rivers without Correction
Evaporation or Storage.
NUMBER OF CONSECUTIVE MONTHS
1 3 6 9 12 15 18 21 24 27 30



NEW ENGLAND WATER WORKS ASSOCIATION

COMMITTEE ON YIELD OF DRAINAGE AREAS

AVERAGE DAILY YIELD OF ONE SQUARE MILE OF DRAINAGE AREA, FOR THE DRIEST PERIODS OF CONSECUTIVE MONTHS

CHIEFLY RIVERS IN NEW ENGLAND AND EASTERN NEW YORK

drainage areas, and that the results obtained upon one cannot be applied indiscriminately to another in order to obtain the probable yield of such drainage area. Such a conclusion makes it necessary to consider how the differences in the yield of different drainage areas can be accounted for, and to ascertain the general laws, as far as they can be ascertained, which affect the application of the yield of one drainage area to another.

Plate IX is intended to show the yield of water supply drainage areas in Massachusetts and Rhode Island, but there is included also, for the purpose of comparison, the yield of Esopus Creek of the New York water supply.

Plate X is intended to show the yield of water supply drainage areas in Connecticut and of the Croton supply in eastern New York, but there is added to the plate the yield of the Stony Brook drainage area of the Cambridge Water Works and the yield of Esopus Creek, to represent the lowest and highest yields recorded during the period under consideration.

Plate XI is mainly for the purpose of showing the yield of rivers, not corrected either for the effect of storage or for the effect of water surfaces; that is to say, the figures given are the actual measurements of the streams without correction. The yield of the Wachusett and Cambridge drainage areas are presented on this plate for the purpose of comparison. It is to be noted that in the majority of cases the discharge of the rivers is based on a rating curve and measurements of the height of the water in the river once or twice a day. There is likely to be a considerable error when this method is used, especially when the streams are covered with ice, and the quantity discharged is likely to be too large rather than too small; moreover, if there are water powers on a stream, causing a variable flow, heights taken at fixed times once or twice a day may not represent the average height during the twenty-four hours.

Especial care is taken to obtain an accurate measurement of the discharge of the Merrimack River,* and at Esopus Creek a special weir has been in use most of the time to measure the discharge.

* The Lawrence records of the Merrimack River discharge are those used in this report. These records have been compared with the Lowell records for the years 1908–1913, and the difference between the discharge per square mile at Lawrence and Lowell by different methods of measurement is not more than 5 per cent.

RELATION BETWEEN PRECIPITATION AND YIELD.

The most important factor affecting the yield or run-off from a drainage area is the amount of precipitation upon it, and this in turn is governed to a very considerable extent by the elevation of the drainage area.

The best proof of the marked effect of differences in the amount of annual precipitation on the per cent. of the precipitation which runs off is furnished by records from the same drainage area under similar conditions in years of high and low precipitation.

The following table shows the results obtained by comparing the years of high and low precipitation on several drainage areas where there are records for a long series of years. In the cases of the Sudbury and Croton drainage areas, where the series of measurements covers a very long period, the highest six years' and the lowest six years' precipitation were used, and in the cases of the Wachusett records and those of the Perkiomen, Neshaminy, and Tohickon creeks, near Philadelphia, where the records cover a shorter period, the highest and lowest four years' precipitation were used.

TABLE 4.

COMPARISON OF RUN-OFF IN YEARS OF HIGH AND LOW PRECIPITATION.

Drainage Area.	Period.	Average Precipitation. Inches.	Average Run-off. Inches.	Per Cent. of Run-off.
Wachusett	Highest 4 yrs.	54.48	29.27	53.7
	Lowest 4 yrs.	38.65	17.08	44.2
	Difference	15.83	12.19	77.0
Sudbury	Highest 6 yrs.	55.17	29.10	52.7
	Lowest 6 yrs.	36.39	13.53	37.2
	Difference	18.78	15.57	82.9
Croton	Highest 6 yrs.	59.42	31.93	53.7
	Lowest 6 yrs.	40.59	18.50	45.6
	Difference	18.83	13.43	71.3
Average of Perkiomen, Neshaminy, and Tohickon	Highest 4 yrs.	55.06	29.16	53.0
	Lowest 4 yrs.	42.35	19.47	46.0
	Difference	12.71	9.69	76.2
All sources	Highest 20 yrs.	56.29	30.00	53.3
	Lowest 20 yrs.	39.29	16.92	43.1
	Difference	17.00	13.08	77.0

The above table shows clearly the very much larger per cent. of run-off when the precipitation is large than when it is small. An analysis of the figures at the bottom of the table, giving the results for all sources, shows that while the per cent. of run-off corresponding to an annual precipitation of 39.29 in. is 43.1, the per cent. of run-off from the additional precipitation, that is, from the difference between the precipitation in the highest and lowest years, is 77.0 per cent. This result is obtained by taking the difference between the run-off for the high and low periods, amounting to 13.08 in., and dividing it by the difference in the precipitation for these periods, amounting to 17.00 in.

It is the very high percentage of run-off from the difference in precipitation which accounts to a considerable extent for the difference in the run-off per square mile of different drainage areas.

While the amount of precipitation is generally the most important factor affecting the amount of run-off from a drainage area, there are other important factors, such as the relative amount of precipitation in different portions of the year, the character of the soil, the temperature of the air, the steepness of the slopes, and the extent to which the areas are forested. The effect of differing amounts of precipitation upon the run-off may be approximated from the comparisons above given, which show that when the annual precipitation varies from 39.29 in. to 56.29 in., 77.0 per cent. of the difference in precipitation is represented by the run-off. This same percentage would not hold with the smaller precipitation during the years under consideration in this report, but it will not be far in error to assume arbitrarily that when the precipitation varies between 35 and 40 inches and between 40 and 45 inches, 65 and 70 per cent., respectively, of the variation will be represented in the run-off, instead of the 77.0 per cent. applicable to the larger precipitation.

It is difficult to differentiate the effect of the other factors, except that relating to the distribution of the precipitation in different portions of the year.

The following table has been prepared to show to what extent the differences in the run-off from different drainage areas during the recent period of dry years can be accounted for by the differences in precipitation, using the computations based on the assumptions

above stated and the further assumption that with 40 in. of annual precipitation the normal flow from an ordinary drainage area during the four years under consideration, from 1908 to 1911, inclusive, would have been 870 000 gal. per day per square mile of land surface.

TABLE 5.

RELATION BETWEEN PRECIPITATION AND YIELD AS COMPUTED AND MEASURED.

Drainage Area.	Average Annual Precipitation during Dry Years. Inches.	Yield of Land Surface in Gal. per Day per Sq. Mile.		
		Computed as Above Described.	Measured.	Difference of Measured from Computed Quantity.
Esopus Creek	46.89	1 099 000	1 415 000	+316 000
Rondout Creek	45.94	1 068 000	1 355 000	+287 000
Croton River	45.89	1 066 000	987 000	—79 000
Holyoke, Manhan River	45.04	1 038 000	1 053 000	+15 000
Westfield, Tillotson Brook	44.63	1 024 000	974 000	—50 000
Waterbury, West Branch of Naugatuck River	43.07	972 000	999 000	+27 000
Worcester, Tatnuck Brook	40.96*	902 000	983 000*	+81 000
Standard Assumed	**40.00**	**870 000**		
Wachusett Reservoir	39.73	862 000	895 000	+33 000
Pawtucket, Abbott Run	39.23	846 000	809 000	—37 000
Schoharie Creek	38.41	821 000	1 170 000	+349 000
Sudbury River	37.98	808 000	676 000	—132 000
Cambridge, Stony Brook	36.67	767 000	565 000	—202 000

By referring to the third column of the table, it will be noted that the yield in gallons per day per square mile of land surface should vary on account of the difference in the amount of annual precipitation from 767 000 to 1 099 000 gal. per day per square mile. The measured yields vary much more than this, and the differences between the computed and measured yields, as given in the last column of the table, result from other causes than the differences in the amount of precipitation as recorded. In a majority of cases the computed and measured yields show an approximate

* This precipitation is based on the average of records at Tatnuck Brook, Lynde Brook, Kettle Brook, and Jefferson, which are, respectively, 1.5, 4.5, 2.5, and 4.0 miles from the center of the Tatnuck Brook drainage area. The yield for the first five months of 1908, as recorded in the Worcester records, appears to be too large, and a yield for these months deduced from the rainfall at Tatnuck Brook, using the percentage of run-off determined for the adjacent Wachusett drainage area, has been used instead.

agreement, but the measured yields of the Catskill Mountain sources are far in excess of those computed, while the reverse is true of the Stony Brook and Sudbury River yields.

DISTRIBUTION OF ANNUAL PRECIPITATION AFFECTS THE AMOUNT OF RUN-OFF.

The distribution of the precipitation throughout the year is an important matter when one is attempting to deduce the run-off from it, because a large per cent. of the precipitation during the colder portions of the year runs off, while during the warmer portions the reverse is true. This is shown by the following table, based upon the records for the years 1908 to 1911 inclusive.

TABLE 6.

PER CENT. OF PRECIPITATION RUNNING OFF IN DIFFERENT PORTIONS OF THE YEAR.

Drainage Area.	PER CENT. RUNNING OFF.		
	December to April.	May, June, and November.	July to October.
Schoharie Creek	107.3	50.4	15.5
Esopus Creek	95.2	60.7	18.5
Rondout Creek	93.6	58.3	19.3
Worcester, Tatnuck Brook	79.2	51.5	14.8
Waterbury, West Branch of Naugatuck River	73.5	43.5	15.6
Wachusett Reservoir	70.2	48.3	15.5
Westfield, Tillotson Brook	69.1	46.7	17.1
Holyoke, Manhan River	68.4	52.8	18.8
Pawtucket, Abbott Run	66.6	36.5	13.4
Croton River	65.0	42.6	15.9
Sudbury River	58.8	31.9	7.7
Cambridge, Stony Brook	52.2	27.3	7.2
Averages, omitting first three and last two	70.3	46.0	15.9

The table shows the per cent. of the precipitation which runs off in different groups of months. The first group covers the period from December to April, inclusive, representing the colder months from December to March, inclusive, and the month of April when

much of the water precipitated in the previous months in the form of snow flows off in the streams.

The second group includes the months of May, June, and November, when the per cent. running off is fairly large, and the third group the months from July to October, inclusive, when the per cent. running off is low.

The table was prepared primarily to show the much larger per cent. running off in the cold months than in the dry portions of the year, and to call attention to the fact that when the precipitation is relatively low in the colder months the yield from a drainage area with a given annual precipitation will be less than with the same annual precipitation when a larger part falls in the cold months.

Before discussing the table along these lines, it is well to note the very high per cent. running off during the colder months from the drainage areas of the three creeks in the Catskill Mountains, while the per cent. running off from these same drainage areas from July to October differs but little from that of most of the other sources. It is, of course, impossible that the run-off should exceed the precipitation upon a drainage area, unless some of the precipitation of previous months is included in the run-off. This frequently happens when one is dealing with the run-off of individual months in the winter and spring, as the snow falling in one month melts and runs off in the succeeding months, but when a group of months is taken, covering practically the whole winter and a sufficient time in the early spring to insure the melting of all of the snow, the run-off for the period will always be less than the precipitation because even in the winter there is a loss of water by evaporation.

The fact that the run-off from Schoharie Creek during the winter months exceeds the recorded precipitation, and that the run-off from Esopus and Rondout creeks during the same months is a very large proportion of the precipitation, represents an unusual condition, and it has been suggested that it may be accounted for in several ways; first, that snow frequently falls upon these mountainous drainage areas in November which does not melt and run off until a subsequent month; second, that it is impracticable to obtain the precipitation upon the higher portions of the

mountains because these places are entirely inaccessible during the winter; and third, that the difficulty of measuring the streams during the winter months in such an extremely cold climate, when much ice forms, may have resulted in recording discharges greater than the actual discharges of the streams.

The first of these suggestions does not seem to have very much weight, because during the period covered by the table there was no noticeable deficiency in the November run-off, as there would have been had much of the November precipitation been in the form of snow which remained on the ground to the end of the month, and the amount of water carried over from November to December in the form of snow would have been largely offset by the greater amount of water stored in the interstices of the ground at the end of April. It is known that there is more water in the ground at the end of April than at the beginning of December, because the streams at times when they are not affected by rains are much higher at the end than at the beginning of this winter period.

The second suggestion that the precipitation upon the tops of the mountains is greater than is indicated by the rainfall records has weight.* As has already been stated, the rain gages are maintained at as high a level as observers can be found, but none of them are located on or near the tops of the highest mountains, and the precipitation is probably much higher upon these mountains than upon the parts of the drainage area represented by the rain gages. It is even supposable that there may be a considerable condensation of moisture from the atmosphere at these high points, especially in winter, which is not represented by any precipitation which can be measured. Even at the higher stations where observers are available it may be impracticable to obtain thoroughly trustworthy records, on account of the high winds in these elevated places and the difficulty of obtaining suitable gage keepers. Winter records of precipitation are more likely to be too low than too high.

* A rain gage was maintained at the top of Mount Washington from 1872 to 1886, the average annual rainfall recorded in this period being 83.53 in., while that at Lake Cochituate for the same period was 42.92 in. A comparison of the annual rainfall from 1876 to 1886, inclusive, on Mount Washington with the same period at Lake Cochituate and on the Sudbury River watershed shows the following results: Mount Washington, 90.13; Lake Cochituate, 42.59; Sudbury River, 44.02.

The third suggestion that the recorded discharge may be too high during the ice period may account to a large extent for the extremely high per cent. running off during the cold months. It is a matter of extreme difficulty to obtain a trustworthy measurement of streams when much ice is forming, not only as a covering over the surface of the streams in places, but as slush and anchor ice.

In addition to these causes for the high per cent. of precipitation recorded as run-off in the winter months, it is probable that the very low temperatures upon these drainage areas greatly reduce the evaporation during these months.

On the whole it seems best, in reaching any general conclusions as to the per cent. running off in different portions of the year, to omit the records of the three Catskill Mountain creeks and of the Sudbury River and Stony Brook drainage areas, which give abnormally high and low results. With these omissions, the average run-off, as shown in the last line of the table, is, during the winter period, 70.3 per cent.; in the months of May, June, and November, 46.0 per cent.; and in the period from July to October, inclusive, 15.9 per cent. Hence, during the years under consideration, an inch of precipitation in the cold months caused a run-off more than four times as great as an inch of precipitation during the period from July to October.

Special attention is called to the per cent. of precipitation running off from the Catskill Mountain drainage areas during the dry period from July to October, inclusive. The percentages as given in the last column of Table No. 6 are, respectively, 15.5, 18.5, and 19.3, averaging 17.8. This is but little larger than the 15.9 per cent. which runs off from ordinary drainage areas, a result which is surprising in view of the steep and somewhat impervious character of these mountain areas and the larger precipitation upon them.

Having shown by the foregoing table and statements that the per cent. running off is so much greater in some portions of the year than in others, it is now important to place on record the distribution of the precipitation upon the drainage areas under consideration for the different parts of the year, and this is done in the following table.

TABLE 7.

DISTRIBUTION OF PRECIPITATION IN DIFFERENT PORTIONS OF YEAR, FROM RECORDS OF 1908–1911, INCLUSIVE.

Drainage Area.	Per Cent of Total Precipitation.		
	December to April.	May, June, and November.	July to October.
Schoharie Creek	42.1	28.0	29.9
Esopus Creek	44.5	23.8	31.7
Rondout Creek	45.6	22.9	31.5
Worcester, Tatnuck Brook	45.7	19.9	34.4
Waterbury, West Branch of Naugatuck River	47.1	20.7	32.2
Wachusett Reservoir	45.4	21.4	33.2
Westfield, Tillotson Brook	42.7	21.5	35.8
Holyoke, Manhan River	45.1	22.3	32.6
Pawtucket, Abbott Run	46.1	23.5	30.4
Croton River	47.1	22.4	30.5
Sudbury River	47.4	22.5	30.1
Cambridge, Stony Brook	45.9	22.2	31.9
Averages	45.4	22.6	32.0

It will be seen by reference to the table that upon all of the drainage areas under consideration the per cent. of precipitation in the different portions of the year is reasonably uniform. This indicates that there is a large territory to which the records of run-off are not made inapplicable by a dissimilar distribution of precipitation. This territory includes practically all drainage areas in Massachusetts, Rhode Island, and Connecticut, with the possible exception of a part of western Massachusetts.

In northern Vermont, however, the distribution of precipitation is very different. As an illustration, the average precipitation for twenty-five years at Lunenberg, Chelsea, Stafford, Woodstock, and Northfield, was 36.36 in., of which 36.9 per cent. fell in the period from December to April; 26.7 per cent. in May, June, and November; and 36.4 per cent. in the period from July to October. With such a distribution of precipitation, the run-off for the year would be less than when the distribution is as shown by the foregoing table.*

* The distribution of precipitation throughout the year is very fully treated in a paper recently presented to the Association by Mr. X. H. Goodnough, entitled, "Rainfall in New England."

By combining the final results given in Tables Nos. 6 and 7, it was found that during the four years under consideration 67.3 per cent. of the whole run-off occurred in the months from December to April inclusive; 21.9 per cent. in the months of May, June, and November; and 10.8 per cent. in the months from July to October inclusive.

COMPARISON OF RECENT AND FORMER DRY PERIODS.

The water-works engineer, as a rule, bases his estimates of the capacity of a given source of water supply upon the records of the driest period known to him, if such period is not too remote, and it is, therefore, of especial interest to know whether the recent dry period furnishes a new basis for estimating the capacity of water supplies.

The researches of the committee warrant the general statement that over a large part, if not the whole, of New England the recent dry period does furnish a new basis, as it is the driest period known since the gaging of streams in this section of the country was begun. Precipitation records indicate that still drier periods occurred prior to the year 1850, but none since that date. Upon the Croton watershed in New York, only a short distance west of the westerly limits of New England, the recent dry period is not quite as dry as the period from 1879–1883.

There is some danger that such a general statement may be misleading. For instance, a community taking a supply from a running stream or one having upon it only a very small reservoir, measures a drought by the quantity of water running in the stream in the driest day, week, or month, and the driest time for short periods may not have occurred in the two dry periods under consideration. The statement is true of periods of six or more consecutive months.

The superintendent of a water works who has a reservoir of moderate size which will surely fill and overflow each spring is concerned only with the amount of water flowing in the driest six to ten months of a single dry year, while one who has control of a water system like that of New York, the Metropolitan Water District, Worcester, and Salem, having reservoirs very

large in proportion to the drainage area feeding them, knows that the winter and spring flow is more important for his works than that of the drier portions of the year. Such supplies are depleted to a much greater extent by a succession of dry years than by one year of extreme drought.

The recent dry period has been extreme both in regard to the low flow during six months or more of a single year and during a long series of consecutive years. The drought in western New England and New York ended with phenomenally heavy rains in the autumn of 1911, but in eastern Massachusetts there was no large increase in the amount of run-off to the end of 1913, and to the present time in 1914 the discharge of the streams is but little above the average.

The only recorded gagings known to the committee, which covered the dry period of 1879 to 1883 and the recent dry period from 1908 to 1912, are those of the Cochituate, Sudbury, and Merrimack River drainage areas in New England and the Croton drainage area in New York. A comparison of the recorded yields of these drainage areas for the two periods is given in the tables which follow. The first table is a comparison of the average yield in million gallons per day per square mile of drainage area for different consecutive dry periods, which are selected with reference to their being the critical periods from the water supply standpoint. The second table shows the relative safe capacity of the sources with various assumed amounts of storage per square mile, and shows more accurately than the first table the relative dryness of the two periods from the water-works point of view.

On both the Sudbury and Croton drainage areas new reservoirs have been constructed and filled between these periods, so that it has been necessary to make corrections for evaporation and to base the tables upon the yield per square mile of land surface. On the Cochituate and Merrimack River drainage areas there have been no important changes, and the records have been used without such corrections.

The comparisons made in Table 8 show plainly that the recent dry period has been drier on the Cochituate, Sudbury, and Merrimack drainage areas than that of 1879–1883, while the reverse is true on the Croton drainage area. For periods varying

TABLE 8.

COMPARISON OF THE DRY PERIODS 1879–1883 and 1908–1912, BASED ON MEAN RUN-OFF DURING PERIODS OF DIFFERENT LENGTHS.

(All quantities in million gallons per day per square mile.)

Length of Dry Period. Months.	COCHITUATE.			SUDBURY.			MERRIMACK.			CROTON.		
	Average Run-off.		Later Period LESS than Former. Per Cent.	Average Run-off.		Later* Period LESS than Former. Per Cent.	Average Run-off.		Later Period LESS than Former. Per Cent.	Average Run-off.		Later Period MORE than Former. Per Cent.
	1879–83.	1908–12.		1879–83.	1908–12.		1879–83.	1908–11.		1879–83.	1908–12.	
6	.137	.102	26	.169	.100	41	.317	.252	21	.168	.200	19
7	.182	.123	32	.182	.138	24	.370	.274	26	.173	.278	61
8	.200	.159	21	.200	.185	8	.380	.279	27	.201	.349	74
9	.252	.237	6	.251	.244	3	.399	.325	19	.239	.404	69
18	.412	.387	6	.486	.405	17	.532	.493	7	.581	.634	9
19	.417	.403	3	.499	.410	18	.571	.509	11	.572	.692	21
20	.440	.420	5	.500	.426	15	.618	.499	19	.567	.734	29
30	.532	.508	5	.691	.493	29	.731	.576	21	.707	.811	15
31	.538	.516	4	.698	.505	28	.730	.581	20	.720	.822	14
32	.544	.526	3	.721	.511	29	.770	.577	25	.742	.823	11
42	.583	.527	10	.758	.555	27	.775	.610	21	.817	.842	3
43	.576	.534	7	.748	.563	25	.767	.612	20	.807	.863	7
44	.574	.540	6	.746	.566	24	.767	.610	20	.799	.870	9

* The differences given in this column would probably have been much smaller if it had been feasible to obtain an accurate measurement of the run-off in 1908–1912.

from nine to forty-four months the mean run-off has been from 3 to 10 per cent. less on the Cochituate drainage area, 3 to 29 per cent. less on the Sudbury drainage area, and 7 to 25 per cent. less on the Merrimack drainage area in the recent than in the former dry period.

In the years 1908–1912, there was practically no extreme drought upon the Croton drainage area for periods of from six to nine months, but for periods of from eighteen to forty-four months the yield, although very low, was from 3 to 29 per cent. greater than in the former dry period.

Such comparisons as those just given are somewhat unsatisfactory because the critical periods from a water-supply standpoint do not have exactly the same length in different years, and a better comparison can be made by computing the safe yields of these drainage areas during the two dry periods, assuming various fixed amounts of storage capacity per square mile of drainage area. For example, let it be assumed that the available storage capacity upon the Cochituate drainage area is 83 500 000 gal. per square mile of drainage area, and assume further that this amount of storage does not change the existing proportion of land and water surfaces. Under these assumed conditions, the safe capacity of the drainage area per square mile would have

TABLE 9.

COMPARISON OF THE DRY PERIODS 1879–1883 AND 1908–1912, BASED ON SAFE CAPACITY OF DRAINAGE AREAS WITH VARYING AMOUNTS OF STORAGE.

(All storage and safe capacities in this table are per square mile of drainage area.)

COCHITUATE (Whole Drainage Area).				SUDBURY (Land Surface).			
Available Storage. Mil. Gal.	Safe Daily Capacity. Gallons per Day.		Later Period LESS than Former. Per Cent.	Available Storage. Mil. Gal.	Safe Daily Capacity. Gallons per Day.		Later* Period LESS than Former. Per Cent.
	1879–83.	1908–12.			1879–83.	1908–12.	
18.2	228 000	200 000	12.3	18.4	208 000	200 000	3.8
37.9	344 000	300 000	12.8	36.8	353 000	300 000	15.0
59.1	441 000	400 000	9.3	56.4	430 000	400 000	7.0
83.5	541 000	500 000	7.6	77.9	518 000	500 000	3.5
175.2	724 000	700 000	3.3	189.0	809 000	700 000	13.5
547.0	911 000	900 000	1.2	313.5	925 000	800 000	13.5

* The differences given in this column would probably have been much smaller if it had been feasible to obtain an accurate measurement of the run-off in 1908–1912.

Merrimack (Whole Drainage Area).				Croton (Land Surface).			
Available Storage. Mil. Gal.	Safe Daily Capacity. Gallons per Day.		Later Period LESS than Former. Per Cent.	Available Storage. Mil. Gal.	Safe Daily Capacity. Gallons per Day.		Later Period MORE than Former. Per Cent.
	1879–83.	1908–12.			1879–83.	1908–12.	
0.9	200 000	200 000	0.0	6.6	177 000	200 000	13.0
8.8	337 000	300 000	11.0	18.4	259 000	300 000	15.8
29.4	477 000	400 000	16.1	36.8	345 000	400 000	15.9
53.7	595 000	500 000	16.0	55.2	426 000	500 000	17.4
123.2	757 000	700 000	7.5	92.0	572 000	700 000	22.4
260.0	961 000	800 000	16.8	117.0	662 000	800 000	20.8
				164.0	836 000	900 000	7.7

been, in the period 1908–1912, 500 000 gal. per day; and in the period 1879–1883, 541 000 gal. per day. With this amount of storage, therefore, the safe capacity in the later period would have been 7.6 per cent. less than in the earlier period.

The table preceding gives the safe capacity of the four drainage areas under consideration, with differing amounts of storage per square mile of drainage area.

DRY PERIODS PRIOR TO 1850.

As the statement has been made that "precipitation records indicate that still drier periods occurred prior to the year 1850," it may be of interest to present a comparison between the yields during some of these periods, as deduced from the precipitation records, and the yield of the Wachusett drainage area during the recent dry period.

The following reliable long-continued precipitation records are available:

New Bedford, Mass.	Record begins in 1814
Boston, Mass.	Record begins in 1818
Amherst, Mass.	Record begins in 1836
Lowell, Mass.	Record begins in 1825
Waltham, Mass.	Record begins in 1826
Providence, R. I.	Record begins in 1832

The period beginning in June, 1837, and extending to the end of October, 1838, was probably from 7 to 15 per cent. drier than

the most intense part of the recent dry period on the Wachusett drainage area — that is, the period from June, 1910, to October, 1911, inclusive. The estimated deficiency during the earlier period is as follows:

New Bedford, Mass.	9	per cent.
Boston, Mass.	3	per cent.
Amherst, Mass.	7	per cent.
Lowell, Mass.	14	per cent.
Waltham, Mass.	3	per cent.
Providence, R. I.	15	per cent.
Average	8.5	per cent.

If, in making the comparison, a longer period had been used, covering the years 1837–1840 and the years 1908–1911, the results would not have been materially changed.

A far drier period even than 1837–1838 is indicated by the precipitation records at Boston for 1821–1822. Comparing the period from June, 1821, to October, 1822, with the period from June, 1910, to October, 1911, on the Wachusett drainage area, it appears that the probable yield in the earlier period would have been 30 per cent. less than in the later one.

The only other records available for this period are those at New Bedford, a study of which does not indicate that the yield at that time was lower than on the Wachusett drainage area in 1910–1911. Other contemporary observations of conditions in 1821–1822 indicate that the flow of streams in eastern New England was very low.

The records of precipitation at Boston and Providence in the years 1832–1833 indicate that the yield of drainage areas in the period from June, 1832, to October, 1833, inclusive, would have been from 7 to 17 per cent. less than from the Wachusett drainage area during the corresponding months in 1910–1911. The records of the precipitation at Lowell and New Bedford in these years indicate a less severe drought at those places than at Boston and Providence.

Precipitation records for 1845–1846 also indicate a very dry period, the precipitation in the later year probably being lower than in any subsequent year up to the present time. During the period from June, 1845, to October, 1846, the yield of the drainage

areas in eastern New England was probably less than that of the Wachusett drainage area in the corresponding months in 1910, 1911, by an amount not exceeding 10 per cent.

Similarly, the observations at Amherst and Providence from June, 1848, to October, 1849, indicate a yield from 2 to 10 per cent. less than that of the Wachusett drainage area in the corresponding period in 1910–1911. The precipitation records in other parts of New England for these years indicate that the drought was quite general throughout a large part of New England.

TABLES AND DIAGRAMS TO FACILITATE COMPUTATION OF SAFE CAPACITY OF SOURCES.

The thirteen tables, which are called " Capacity Tables," given subsequently, and the twelve diagrams which show graphically the results shown by twelve of the tables, are presented to facilitate the computation of the so-called " safe capacity " of sources of water supply. The tables should be used with judgment, and attention is called to a subsequent section entitled **" Caution,"** and to Appendix No. 2 (page 525) which explains the method used for their computation.

They are intended to show the storage capacity required to supply in the driest periods various quantities of water daily from one square mile of drainage area containing water surfaces varying from 0 to 15 per cent., and may be used when the storage capacity is known to determine the safe daily capacity of the sources of supply, or may be used equally well to deduce the required storage capacity when the daily quantity of water desired is known.

It needs but little explanation to show how the tables may be used. The first column gives the constant daily quantity of water to be drawn from the source, in gallons per square mile of drainage area, including water surfaces. The remaining columns show the quantity of storage required per square mile of drainage area in order to provide the constant daily quantity given in the first column, when there are water surfaces amounting to 0, 5, 10, and 15 per cent. of the total drainage area.

The quantity of storage required for other percentages of water

surface may easily be obtained by interpolation, or directly from the diagrams.

TABLE 10.

AVERAGE ELEVATIONS OF DRAINAGE AREAS.

Drainage Area.	Average Elevation above Sea Level. Feet.	Drainage Area. Sq. Miles.	Period Covered.
Cambridge, Stony Brook...	180	23.57	1908–1912
Pawtucket, Abbott Run....	150	26.94	1908–1912
Metropolitan Water Works:			
Sudbury River.....	300	75.20	1879–1884
Sudbury River.....	300	75.20	1908–1912
Wachusett Reservoir....	750	118.19	1908–1914
Worcester, Tatnuck Brook.	950	5.231	1908–1912
Holyoke, Manhan River...	950	13.00	1900, 1908–1911
Westfield, Tillotson Brook..	990	5.84	1908–1911
Waterbury, West Branch of Naugatuck River.....	890	18.00	1908–1912
Hartford Reservoirs.....	460	11.92	1909–1912
New York Water Works:			
Croton River.....	620	338.8	1879–1883
Croton River.....	600	360.4	1908–1913
Esopus Creek.....	1700	239.0	1908–1913

The characteristics of these drainage areas are fully described in Appendix No. 1, but a brief statement regarding them is inserted in this place.

Cambridge, Stony Brook. This drainage area probably gives the smallest yield of any of those from which records were received, but the low yield as given in the records and as reflected in the capacity table for this source is due in part to certain losses of water by leakage and by evaporation from swamps, which are not accounted for in the computations. In nearly all cases the capacity of a source based upon these records will be lower than the actual capacity of the source.

Pawtucket, Abbott Run. The results appear to be accurate.

Metropolitan Water Works, Sudbury River. The records of the dry period 1879–1883 are accurate, but they represent a period not quite as dry as the recent dry period. The records of 1908–1912 are probably not accurate, especially for periods of eight months or less, and the capacity of a source based upon these records will be as a rule too low.

Metropolitan Water Works, Wachusett Reservoir. These records are unusually accurate. They represent a drainage area having a large percentage of water surfaces and large storage capacity, and for this reason are not as applicable to drainage areas having a small percentage of water surfaces and small storage as are many of the other records.

Worcester, Tatnuck Brook. The records appear to be accurate except when the water is flowing over the spillway, at which time the results appear to be rather high. During the critical period upon which the greater part of the capacity table is based there was little or no water flowing over the spillway. In cases where there is a very large storage per square mile of drainage area, the results based on this capacity table may be somewhat too large. The drainage area is only about 5 square miles — so small that it is more difficult to obtain accurate results than from a larger drainage area.

Holyoke, Manhan River. The records appear to be accurate.

Westfield, Tillotson Brook. The records appear to be accurate. It is a disadvantage that the drainage area is only about six square miles.

Waterbury, Naugatuck River. The records appear to be accurate, but some of the water wasted is at times discharged through a blow-off, and the measurement at such times is only approximate. Upon the Croton drainage area, which is not far distant from Waterbury, the recent drought was not as severe as that of the years 1879–1883, and it is quite likely that the drought at Waterbury was not as severe as in most parts of New England.

Hartford Reservoirs. The accurate records begin in June, 1909, and consequently the records of the whole of the dry period which began in June, 1908, are not available. This does not affect the capacity table, except in the portions which relate to highly developed sources, and the safe capacity deduced from the table in such cases will probably be larger than if the records had been available from June 1, 1908.

New York Water Works, Croton River. These are standard records and are supposed to be trustworthy. Two capacity tables are furnished. That covering the years 1879–1883 represents a lower yield than that covering the period 1908–1913; consequently,

the latter table is of little value. The storage capacity and area of water surfaces increased greatly between the two periods.

New York Water Works, Esopus Creek. The records are accurate when there is no ice in the streams, and fairly good at such times. The drainage area is at a far greater elevation above the sea than most of the drainage areas, and consequently has a high precipitation and a run-off far in excess of ordinary drainage areas. It is also probable that the drought was not as severe here as in New England.

As a general rule, it is desirable in making computations of the capacity of sources to exclude the records based upon Stony Brook, Sudbury River 1908–1912, Croton River 1908–1913, and Esopus Creek; also in determining the safe capacity of drainage areas with very small water surfaces to give little weight to or to exclude the results obtained from drainage areas having large water surfaces.

CAUTION.

While the capacity tables have been computed on the basis of the records of the yield of different drainage areas during the recent period of extremely dry years, and are in general correct and the best basis for computing the yield of other drainage areas, they are not, when each table is considered as a whole, equally good, and different parts of the same table are not equally trustworthy.

The principal causes of inaccuracy, aside from those already noted in the comments upon the different drainage areas above given, are given below. The first two affect chiefly the larger figures in the tables and the last three the smaller figures; the intermediate figures are not affected in all cases. The causes of these inaccuracies are:

1. Basing the estimate of required storage for highly developed sources on records extending from 1908 to 1911 or 1912, instead of to 1914 or later.

2. Using some records which do not represent the driest period of years.

3. Basing computations on monthly instead of daily yield.

4. Deducing small yields of land surfaces from records of drainage areas having large reservoirs.

5. Assuming that the recent period of dry years includes the driest period of only a few months.

Besides the above causes of inaccuracy, which need to be considered under some circumstances, special caution should be used in applying any records to very small drainage areas with small storage capacity.

1. Inaccuracy which may result from basing the estimate of required storage for highly developed sources on records extending from 1908 to 1911 or 1912, instead of to 1914 or later.

The statistics were in most cases collected only from 1908 to the end of February, 1912, as these years represent the extremely dry period. With a drainage area developed with an extremely large amount of storage this period is too short to give correct results in eastern Massachusetts and in Rhode Island. For instance, when the records of the Wachusett Reservoir were available only to February, 1912, the amount of storage required to provide for a daily draft of 1 050 000 gal. per day per square mile of land surface was computed to be 338 million gal. After the records became available to the end of January, 1914, the required amount of storage was computed to be 394 million gal. The 338 million gal. first determined would by the revised table correspond to a daily draft of 1 023 000 instead of 1 050 000 gal., a difference of 2.6 per cent.

In New York and in New England west of the Connecticut River, there is probably little or no inaccuracy from this cause, as the dry period was ended abruptly by very heavy precipitation in the month of October, 1911.

2. Inaccuracy due to using some records which do not represent the driest period of years.

Among the capacity tables given are those based on the Croton records of 1908–1913, which is known not to represent as dry a period as the years 1879–1883, for the same drainage area.

There are no records to show whether or not the Waterbury records represent a period of extreme drought, but from the nearness of the Waterbury to the Croton drainage area it is likely that

they do not include the driest period which has occurred within the last sixty years.

As the Sudbury records for 1908–1912 do not appear to be trustworthy, a capacity table has been based upon the records for the years 1879–1884, although the yield during this period was somewhat greater than during the later period.

If the tables mentioned are used, some deduction should be made from the computed daily quantity if it is desired to obtain the safe capacity of the source for a period corresponding to the driest that has occurred in the past sixty years. This statement relates mainly to highly developed drainage areas.

3. Inaccuracy due to basing computations on monthly instead of daily yield.

When the critical period used in computing the capacity tables extends over only a few months there is often an inaccuracy arising from the use of monthly instead of daily records, because the month preceding or that succeeding the critical period, although giving a high average yield, may contain a number of days of very low yield which affect the amount of storage capacity required, and if these days had entered into the computation the required amount of storage corresponding to a given daily draft would be increased. This source of inaccuracy has a diminishing importance as the length of the critical period increases, but it is advisable in every case in making computations to assume as *available* storage less than the whole amount. It is better to adopt the safer policy of assuming that a month's supply of water, even though available for use, is not to be reckoned as available storage when making computations.

4. Inaccuracy resulting from deducing yields of land surfaces in short dry periods from records of drainage areas having large reservoirs.

When an attempt is made to obtain the yield from land surfaces during a period of very dry months from a drainage area like the Wachusett and from others having large reservoirs, it is necessary to make a large correction for evaporation, which as applied to individual months is uncertain in amount. In addition, the water in a reservoir which is in use lowers a considerable distance during such dry months, and some water is then draining from the inter-

stices of the ground into the reservoir of which no account is taken in the records.

To avoid inaccuracies due to these causes one should, for determining the safe capacity of sources with small reservoirs and small water surfaces, use the tables deduced from drainage areas having such reservoirs and water surfaces.

5. Inaccuracy due to assumption that the recent period of dry years includes the driest period of only a few months.

This report deals as a rule with the dry period 1879–1884 and the recent dry period beginning in 1908. The Manhan River records show that drier months occurred in 1900 than during the recent dry period, and these months have been used in preparing the table for that drainage area. It is not unlikely that in the years for which records are not available there are some drier short periods than have been used as a basis for the tables, but it is not probable that there have been even short periods very much drier than those upon which the tables are based.

In addition to the possible inaccuracies above enumerated, it is well for the engineer to be very conservative in applying any records to a very small drainage area with small storage capacity. This is not because there will not be, in the long run, substantially the same precipitation and the same amount of run-off per square mile from the small drainage area as from a large one, but because of the many uncertainties connected with a drainage area of less than, say, one square mile. The size of such an area may be somewhat indeterminate, especially if it is flat, because the watershed boundary of the ground water may not coincide with the limits of the superficial watershed.

A deficiency of precipitation may be somewhat more pronounced upon a small drainage area than upon a large one, because upon the larger area there may be showers which affect parts of the drainage area even though they do not affect the whole, while such showers may or may not fall on a small drainage area.

Of greater importance, however, is the amount of water which may be lost by percolation underground or by leakage past a dam. Such percolation or leakage, which would represent only a very small part of the yield of a large drainage area, may represent an important part of the yield of a small area.

The chances are, therefore, that the quantity of water which can be *depended upon* from a small drainage area in an extremely dry period will be materially less in proportion to the size than from a large one.

TABLE 11.

CAMBRIDGE WATER WORKS, STONY BROOK, 1908–1912.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0.9	4.6	14.6	25.3
100 000	6.1	12.9	22.5	34.4
150 000	15.1	22.1	31.7	43.6
200 000	24.3	31.3	42.4	53.7
250 000	34.4	41.9	53.1	64.4
300 000	45.2	52.7	63.8	75.1
350 000	56.4	64.9	74.5	85.8
400 000	68.6	77.2	86.0	107.0
450 000	80.9	89.4	109.0	134.0
500 000	93.1	113.0	137.0	170.0
550 000	115.0	140.0	184.0	232.0
600 000	150.0	199.0	246.0	295.0
650 000	212.0	261.0	308.0	357.0
700 000	275.0	323.0	371.0	419.0
750 000	340.0	388.0	435.0	483.0
800 000	409.0	457.0	503.0	
850 000	477.0	525.0		
900 000	546.0			

The amounts of storage given by this table are probably somewhat excessive even for drainage areas at a low elevation near the coast line, as there are extensive swamps on the drainage area of which no account was taken when computing the loss by evaporation, and there were other small losses from leakage and otherwise which are not accounted for in the records.

TABLE 12.

PAWTUCKET WATER WORKS, ABBOTT RUN, 1908–1912.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	2.6	11.6	22.5
100 000	1.8	7.4	16.8	28.7
150 000	5.5	14.9	24.5	34.8
200 000	13.2	22.7	32.1	41.8
250 000	20.8	30.3	39.8	49.4
300 000	29.4	38.7	48.0	59.8
350 000	38.6	47.8	57.3	72.0
400 000	47.8	57.0	69.6	84.3
450 000	57.0	66.9	81.8	97.3
500 000	66.2	79.1	94.1	111.0
550 000	76.4	91.6	108.0	135.0
600 000	90.3	108.0	135.0	164.0
650 000	108.0	137.0	164.0	202.0
700 000	137.0	166.0	206.0	246.0
750 000	169.0	209.0	250.0	290.0
800 000	213.0	253.0	294.0	337.0
850 000	257.0	298.0	343.0	399.0
900 000	301.0	351.0	406.0	462.0
950 000	357.0	413.0	468.0	536.0
1 000 000	419.0	484.0	551.0	
1 050 000	501.0			

TABLE 13.

METROPOLITAN WATER WORKS, SUDBURY RIVER, 1879–1884.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	0	2.9	10.0
100 000	0.4	0.7	5.9	13.0
150 000	2.0	3.8	9.5	18.0
200 000	5.7	9.2	16.1	25.2
250 000	14.9	19.5	24.1	35.7
300 000	25.4	30.2	37.0	46.2
350 000	36.7	40.9	47.7	56.9
400 000	49.0	52.4	58.4	68.4
450 000	61.2	64.7	70.3	80.6
500 000	73.5	76.9	82.6	92.9
550 000	85.8	89.2	95.8	105.0
600 000	98.0	103.0	110.0	125.0
650 000	110.0	117.0	131.0	156.0
700 000	124.0	138.0	161.0	187.0
750 000	153.0	169.0	192.0	223.0
800 000	183.0	199.0	238.0	307.0
850 000	214.0	255.0	322.0	390.0
900 000	271.0	338.0	405.0	
950 000	357.0	422.0		
1 000 000	442.0			

TABLE 14.

METROPOLITAN WATER WORKS, SUDBURY RIVER, 1908–1912.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0.9	3.9	13.0	22.0
100 000	3.4	10.1	19.2	28.2
150 000	9.5	17.0	25.3	34.3
200 000	18.4	24.7	32.1	40.5
250 000	27.6	33.9	40.8	47.7
300 000	36.8	43.1	50.0	56.9
350 000	46.0	52.3	59.2	68.8
400 000	56.4	62.0	71.3	81.1
450 000	67.1	74.2	83.5	96.1
500 000	77.8	86.5	99.6	125.0
550 000	89.2	105.0	129.0	156.0
600 000	110.0	134.0	167.0	203.0
650 000	143.0	178.0	219.0	267.0
700 000	189.0	234.0	282.0	331.0
750 000	235.0	298.0	346.0	395.0
800 000	314.0	362.0	410.0	
850 000	381.0	428.0		
900 000	448.0			

TABLE 15.

METROPOLITAN WATER WORKS, WACHUSETT RESERVOIR, 1908–1914.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	0	2.7	10.8
100 000	0	0.2	5.8	15.4
150 000	0	3.0	9.9	20.0
200 000	1.3	6.1	14.5	24.6
250 000	4.1	10.6	20.1	32.0
300 000	8.7	16.7	26.2	39.6
350 000	15.1	23.3	33.0	47.3
400 000	23.2	31.3	40.7	54.9
450 000	32.4	40.5	49.1	62.6
500 000	41.6	49.7	58.3	71.2
550 000	50.8	58.9	67.6	80.9
600 000	60.0	68.1	81.4	104.0
650 000	69.2	81.4	104.0	130.0
700 000	82.0	104.0	127.0	156.0
750 000	106.0	128.0	153.0	182.0
800 000	131.0	153.0	179.0	208.0
850 000	155.0	177.0	205.0	254.0
900 000	180.0	208.0	261.0	350.0
950 000	210.0	275.0	365.0	454.0
1 000 000	290.0	379.0	468.0	557.0
1 050 000	394.0	483.0	572.0	
1 100 000	497.0	586.0		
1 150 000	601.0			

TABLE 16.

WORCESTER, TATNUCK BROOK, 1908–FEBRUARY, 1912.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	0.8	4.3	8.2
100 000	.0	2.4	5.9	12.3
150 000	0	3.9	10.2	18.5
200 000	2.0	8.1	16.3	24.6
250 000	6.0	14.3	22.5	30.8
300 000	12.2	20.4	28.7	39.7
350 000	19.0	26.6	37.3	48.9
400 000	26.6	34.9	46.5	58.0
450 000	34.3	44.1	55.6	67.2
500 000	43.4	53.7	64.8	76.3
550 000	54.1	64.4	74.9	85.4
600 000	64.8	75.1	85.6	95.9
650 000	75.5	85.8	96.3	107.0
700 000	86.2	96.5	107.0	117.0
750 000	97.0	107.0	118.0	138.0
800 000	109.0	118.0	135.0	164.0
850 000	122.0	132.0	161.0	198.0
900 000	134.0	158.0	195.0	240.0
950 000	155.0	192.0	238.0	283.0
1 000 000	188.0	234.0	280.0	326.0
1 050 000	232.0	277.0	325.0	387.0
1 100 000	276.0	326.0	387.0	
1 150 000	326.0	388.0		
1 200 000	388.0			

TABLE 17.

HOLYOKE WATER WORKS, MANHAN RIVER, 1900, 1908–1911.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	2.0	6.4	12.7
100 000	0.6	3.8	10.5	18.1
150 000	2.1	8.4	15.1	25.7
200 000	6.8	13.7	22.7	33.4
250 000	12.9	19.8	30.4	41.0
300 000	19.1	27.4	38.0	48.7
350 000	25.2	35.0	45.7	56.3
400 000	36.9	42.8	53.3	64.0
450 000	49.1	54.9	61.0	71.6
500 000	61.2	67.1	72.9	79.3
550 000	73.4	79.2	85.1	90.9
600 000	85.5	91.4	97.2	103.0
650 000	97.7	104.0	109.0	116.0
700 000	110.0	116.0	122.0	139.0
750 000	122.0	128.0	145.0	162.0
800 000	134.0	151.0	168.0	185.0
850 000	157.0	174.0	191.0	208.0
900 000	180.0	197.0	213.0	231.0
950 000	203.0	220.0	236.0	256.0
1 000 000	226.0	243.0	260.0	292.0
1 050 000	249.0	266.0	303.0	353.0
1 100 000	272.0	315.0	364.0	414.0
1 150 000	326.0	376.0	425.0	
1 200 000	387.0	437.0		
1 250 000	448.0			

TABLE 18.

WESTFIELD, TILLOTSON BROOK,* 1908–1911.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	0	4.0	10.1
100 000	0	1.2	6.9	15.7
150 000	0	4.2	13.0	21.9
200 000	1.7	10.3	19.2	28.0
250 000	7.7	16.5	25.3	34.2
300 000	13.9	22.6	31.5	40.3
350 000	20.0	28.8	37.6	46.5
400 000	26.2	34.9	43.8	52.6
450 000	32.3	41.1	50.0	58.8
500 000	38.6	47.2	56.1	64.9
550 000	50.8	58.0	65.2	72.4
600 000	62.9	70.2	77.3	84.6
650 000	75.1	82.4	89.4	106.0
700 000	87.2	94.5	111.0	128.0
750 000	99.4	116.0	133.0	151.0
800 000	121.0	139.0	156.0	174.0
850 000	144.0	161.0	179.0	197.0
900 000	166.0	184.0	203.0	238.0
950 000	189.0	210.0	247.0	296.0
1 000 000	212.0	259.0	308.0	357.0
1 050 000	271.0	320.0	369.0	418.0
1 100 000	332.0	381.0	430.0	
1 150 000	393.0	442.0		
1 200 000	454.0			

* For later figures see note on page 471.

TABLE 19.

WATERBURY WATER WORKS, WEST BRANCH OF NAUGATUCK RIVER, 1908–1911.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0.6	8.3	20.0	31.7
100 000	5.2	14.3	26.1	37.8
150 000	9.8	20.4	32.2	44.0
200 000	16.8	27.0	38.3	50.0
250 000	24.5	34.6	45.2	56.2
300 000	32.2	43.2	54.4	65.3
350 000	41.4	52.3	63.5	74.5
400 000	51.6	61.5	72.7	83.6
450 000	62.3	72.1	82.2	92.8
500 000	73.0	82.8	92.9	103.0
550 000	83.7	93.5	104.0	114.0
600 000	94.4	104.0	114.0	124.0
650 000	105.0	115.0	125.0	135.0
700 000	116.0	126.0	136.0	146.0
750 000	127.0	136.0	146.0	158.0
800 000	137.0	147.0	161.0	181.0
850 000	148.0	165.0	184.0	212.0
900 000	168.0	187.0	215.0	255.0
950 000	191.0	218.0	257.0	304.0
1 000 000	221.0	261.0	312.0	365.0
1 050 000	265.0	319.0	372.0	427.0
1 100 000	326.0	380.0	436.0	
1 150 000	389.0	444.0		
1 200 000	453.0			

TABLE 20.

HARTFORD RESERVOIRS, JUNE, 1909–1912.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity, Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0.9	5.4	17.6	31.1
100 000	1.6	11.9	25.2	38.7
150 000	6.8	19.6	32.9	46.4
200 000	13.8	27.2	40.5	54.0
250 000	21.4	34.9	48.2	61.6
300 000	29.3	42.5	55.8	69.3
350 000	38.4	50.7	63.5	77.0
400 000	47.6	59.8	72.1	84.6
450 000	56.7	69.0	81.3	93.7
500 000	65.9	78.2	90.4	103.0
550 000	75.0	87.3	99.6	112.0
600 000	84.2	96.4	109.0	121.0
650 000	93.3	106.0	118.0	136.0
700 000	104.0	115.0	133.0	162.0
750 000	115.0	131.0	159.0	188.0
800 000	129.0	157.0	185.0	223.0
850 000	154.0	183.0	222.0	266.0
900 000	180.0	221.0	264.0	308.0
950 000	220.0	263.0	307.0	
1 000 000	262.0	306.0		
1 050 000	306.0			

TABLE 21.

New York Water Works, Croton River, 1879–1883.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	3.6	9.4	15.3
100 000	1.4	6.6	12.4	20.7
150 000	3.9	9.7	17.1	26.8
200 000	9.5	14.2	23.9	33.0
250 000	16.5	24.0	31.6	42.4
300 000	27.2	34.7	42.9	54.1
350 000	37.9	45.4	55.1	66.4
400 000	48.8	56.1	67.4	78.6
450 000	61.0	68.4	79.6	90.9
500 000	73.3	80.6	91.9	103.0
550 000	85.8	94.4	104.0	115.0
600 000	99.6	108.0	117.0	128.0
650 000	113.0	122.0	131.0	140.0
700 000	127.0	136.0	144.0	153.0
750 000	141.0	150.0	158.0	167.0
800 000	155.0	163.0	172.0	186.0
850 000	173.0	188.0	202.0	222.0
900 000	203.0	218.0	253.0	300.0
950 000	243.0	290.0	337.0	384.0
1 000 000	327.0	374.0	420.0	467.0
1 050 000	410.0	457.0		
1 100 000	494.0			

TABLE 22.

NEW YORK WATER WORKS, CROTON RIVER, 1908–1913.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0.3	2.1	6.2	16.0
100 000	1.8	4.3	12.3	22.1
150 000	3.6	8.6	18.5	28.3
200 000	6.6	14.8	24.6	34.4
250 000	11.1	20.9	30.8	40.6
300 000	18.4	27.1	36.9	46.7
350 000	27.6	35.0	43.1	52.9
400 000	36.8	44.2	51.7	59.1
450 000	46.0	53.4	60.9	68.3
500 000	55.2	62.6	70.1	78.1
550 000	64.4	71.8	79.3	88.8
600 000	73.6	81.0	88.5	99.5
650 000	82.8	90.2	98.9	110.0
700 000	92.0	99.4	110.0	124.0
750 000	102.0	111.0	129.0	149.0
800 000	117.0	134.0	153.0	173.0
850 000	139.0	159.0	178.0	197.0
900 000	164.0	183.0	202.0	235.0
950 000	188.0	209.0	253.0	296.0
1 000 000	226.0	270.0	314.0	357.0
1 050 000	287.0	331.0	375.0	417.0
1 100 000	348.0	392.0	436.0	
1 150 000	409.0			

This table does not represent as dry a period as the preceding one based on the run-off for the years 1879–1883, and consequently has little value.

TABLE 23.

NEW YORK WATER WORKS, ESOPUS CREEK, 1908–1913.

Table showing Storage Capacity Required to Supply Different Quantities of Water Daily from One Square Mile of Drainage Area containing Various Percentages of Water Surface.

Daily Quantity. Gallons.	Required Storage Capacity in Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
50 000	0	1.9	5.6	9.9
100 000	0	3.5	8.1	13.0
150 000	2.2	6.6	11.2	16.0
200 000	5.3	9.7	16.4	23.6
250 000	9.7	17.0	24.0	31.2
300 000	17.4	24.6	31.7	38.9
350 000	25.1	32.3	39.3	46.5
400 000	32.8	40.0	47.0	54.2
450 000	41.4	47.6	54.6	61.8
500 000	50.6	55.6	62.3	69.5
550 000	59.8	64.8	69.9	77.1
600 000	69.0	74.0	79.1	84.8
650 000	78.2	83.2	88.3	93.5
700 000	87.4	92.4	97.5	103.0
750 000	96.6	102.0	107.0	112.0
800 000	106.0	111.0	116.0	121.0
850 000	115.0	120.0	125.0	132.0
900 000	124.0	129.0	135.0	142.0
950 000	133.0	138.0	145.0	153.0
1 000 000	143.0	148.0	156.0	177.0
1 050 000	152.0	159.0	173.0	203.0
1 100 000	162.0	170.0	199.0	228.0
1 150 000	173.0	196.0	225.0	254.0
1 200 000	193.0	222.0	251.0	280.0
1 250 000	218.0	248.0	277.0	306.0
1 300 000	244.0	274.0	303.0	332.0
1 350 000	270.0	299.0	328.0	374.0
1 400 000	296.0	325.0	370.0	435.0

This table gives a smaller amount of storage, and consequently a larger daily quantity, than should be adopted in practice, for the reason that the extreme drought which occurred in New England was not so severe upon this drainage area, and the further reason that the measurements of the discharge of Esopus Creek on account of ice conditions were not as precise as they will be in the future when the reservoirs will be filled and the effect of such conditions will not be felt.

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface.

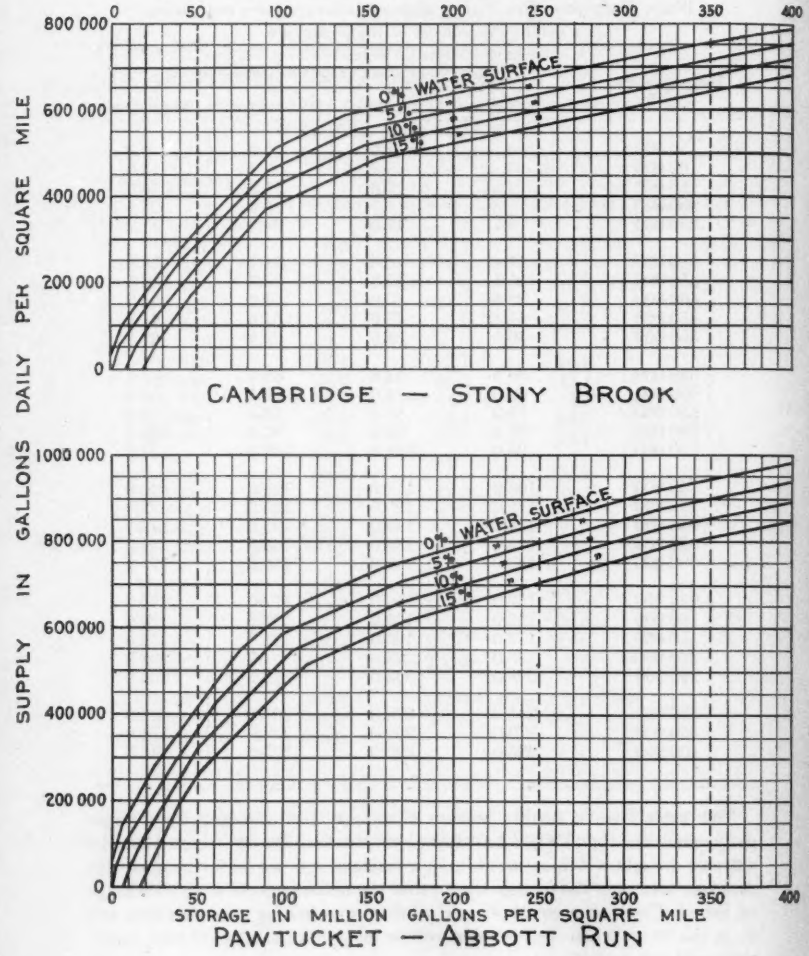


Fig. 1.

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface

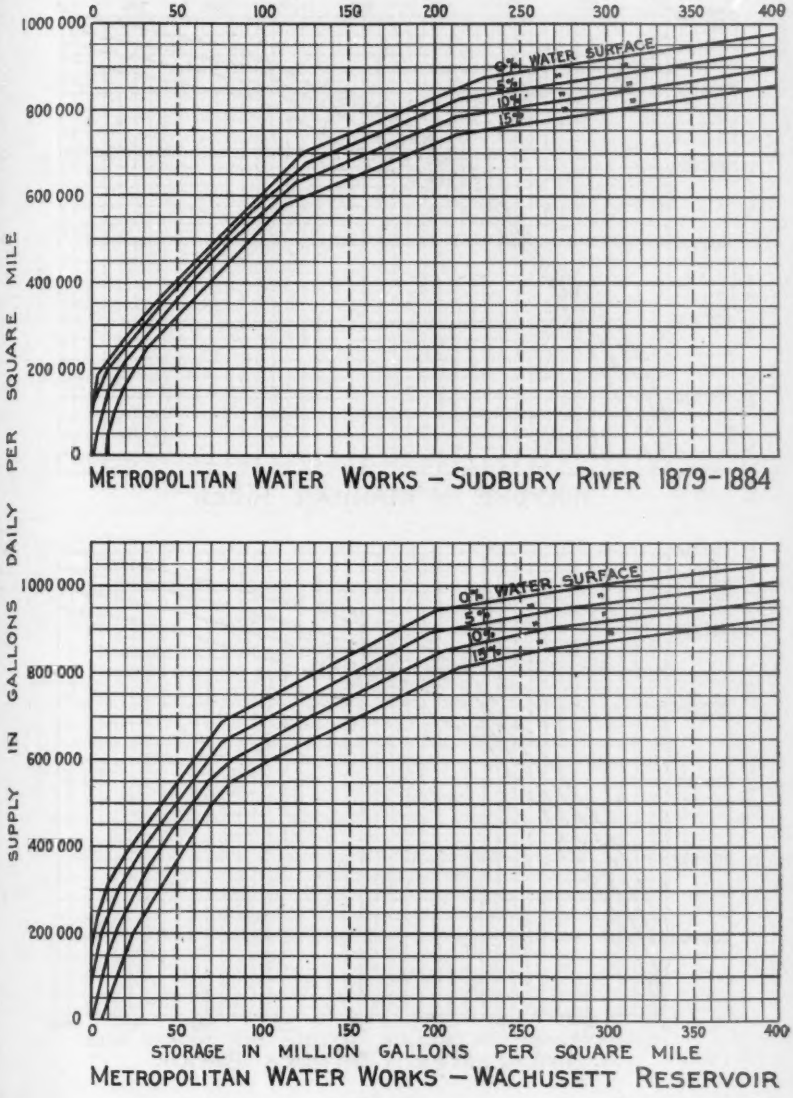


FIG. 2.

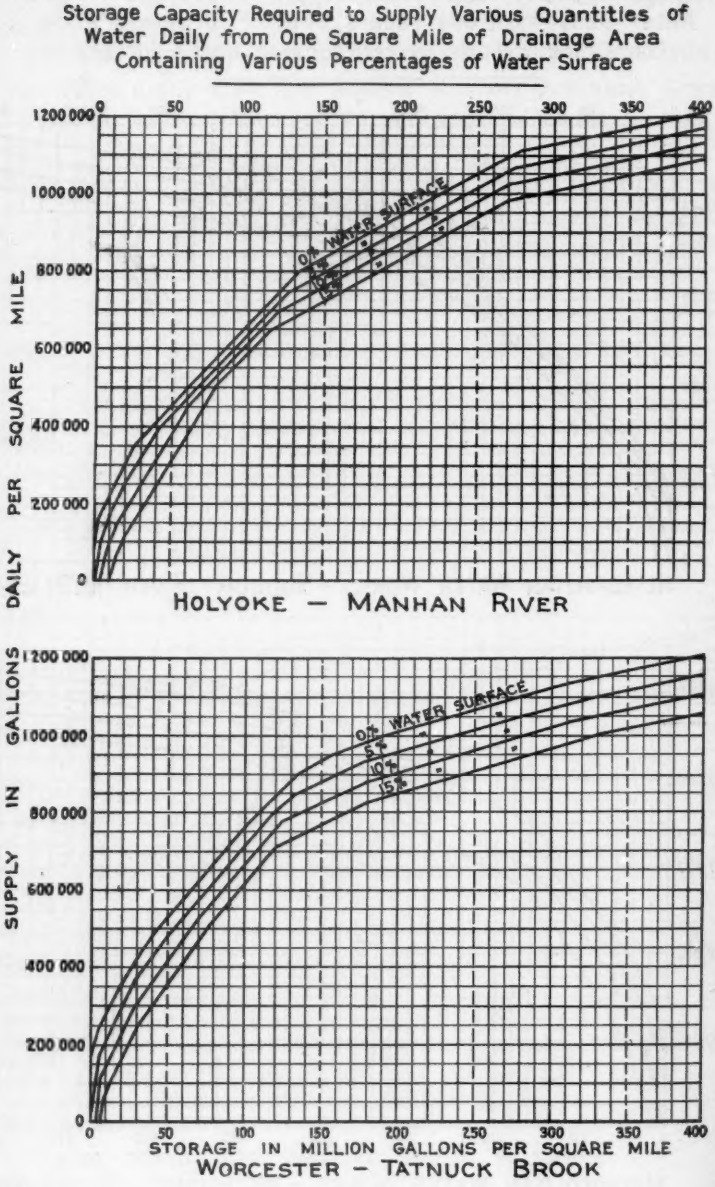
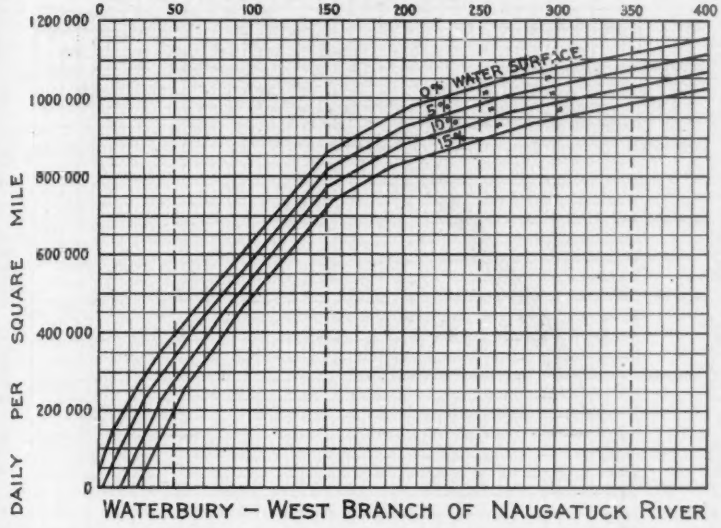

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface
DAILY SUPPLY IN GALLONS PER SQUARE MILE
1200 000
1000 000
800 000
600 000
400 000
200 000
0
50
100
150
200
250
300
350
400
0% WATER SURFACE
5%
10%
15%
HOLYOKE — MANHAN RIVER
STORAGE IN MILLION GALLONS PER SQUARE MILE
WORCESTER — TATNUCK BROOK

FIG. 3.

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface.



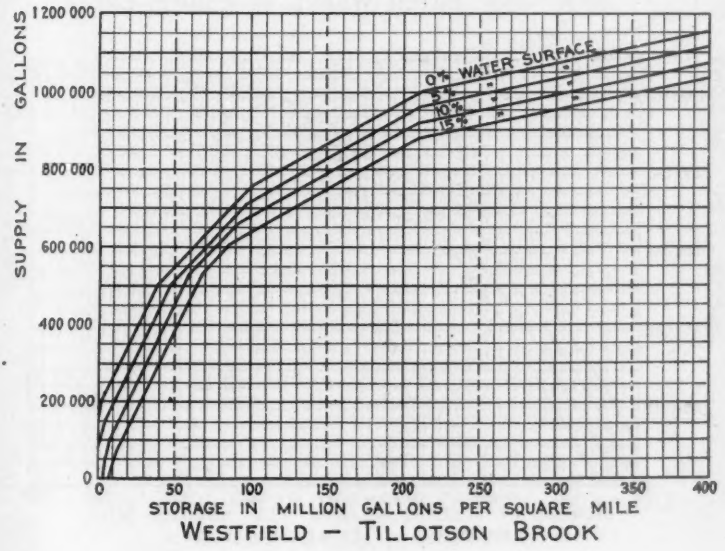


FIG. 4.

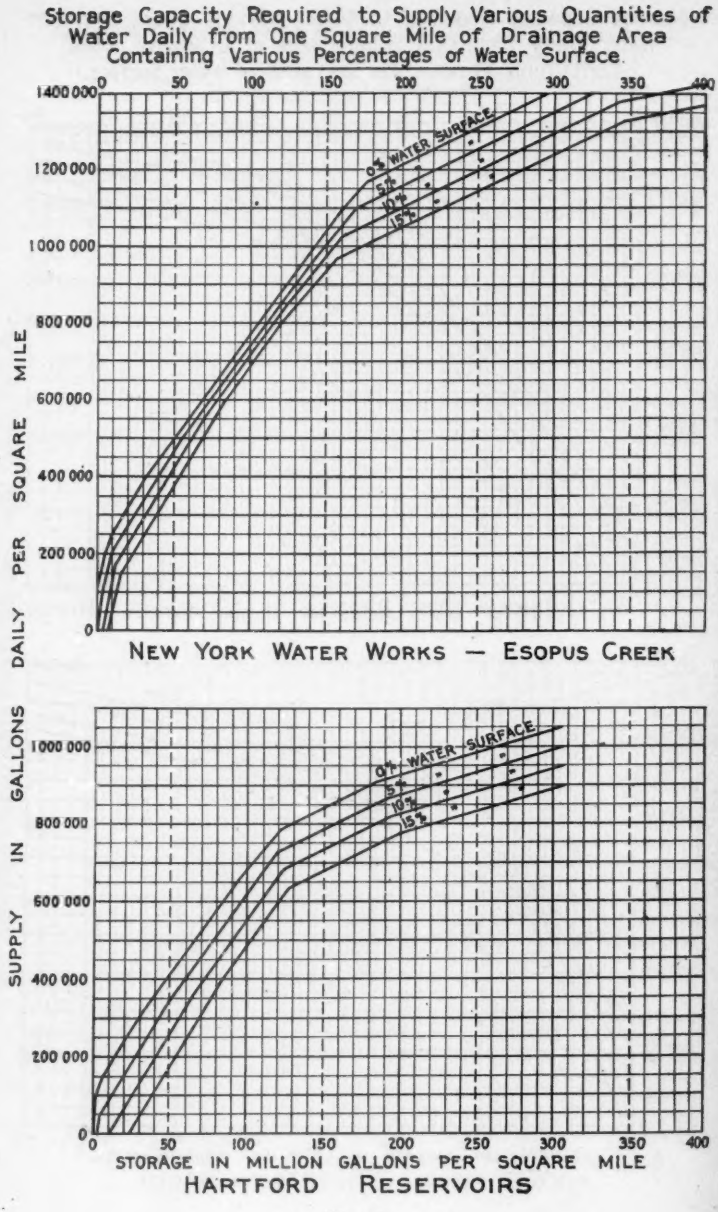

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface.
DAILY PER SQUARE MILE
1400 000
1200 000
1000 000
800 000
600 000
400 000
200 000
0
0
50
100
150
200
250
300
350
400
0% WATER SURFACE
5%
10%
15%
NEW YORK WATER WORKS — ESOPUS CREEK
SUPPLY IN GALLONS
1000 000
800 000
600 000
400 000
200 000
0
0
50
100
150
200
250
300
350
400
0% WATER SURFACE
5%
10%
15%
STORAGE IN MILLION GALLONS PER SQUARE MILE
HARTFORD RESERVOIRS

FIG. 5.

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface.

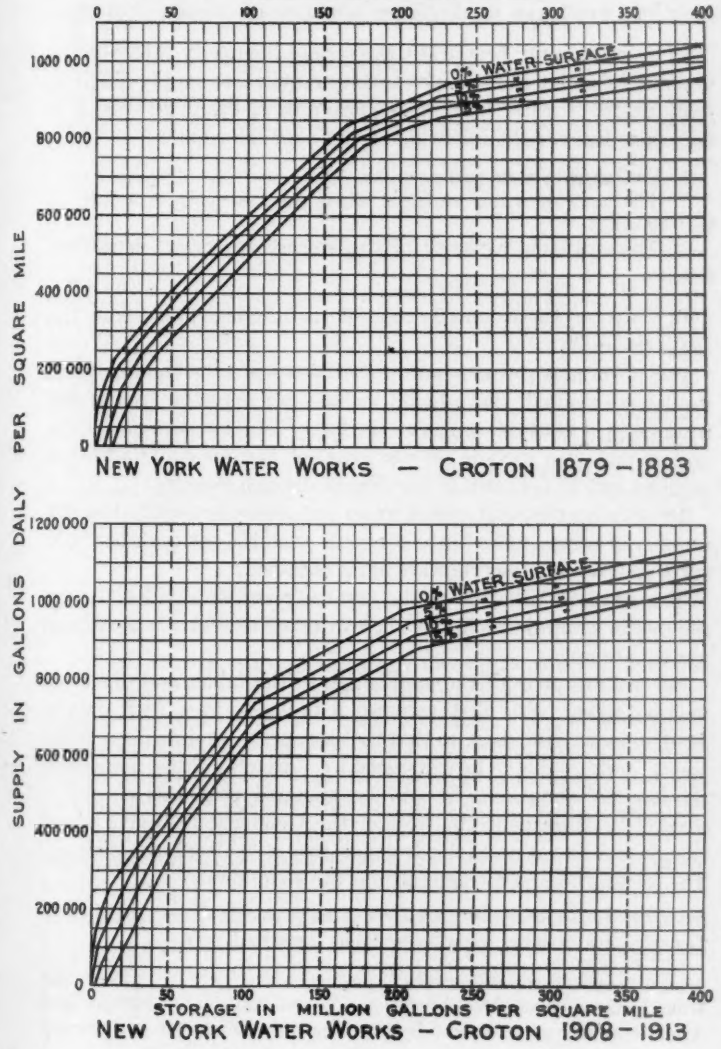


FIG. 6.

HOW TO USE THE "CAPACITY TABLES" AND DIAGRAMS FOR COMPUTING THE SAFE CAPACITY OF SOURCES OF WATER SUPPLY.

In order to apply practically the series of capacity tables or the diagrams showing the storage capacity required to supply different daily drafts of water from one square mile of drainage area, it is necessary to have the following preliminary information:

1. Drainage area in square miles.
2. The area of water surfaces when the reservoirs are full, in square miles.
3. The available capacity of the storage reservoir, in million gallons.

In addition, the mean elevation of the drainage area above the sea is desirable.

In determining the area of water surfaces when the most accurate results are desired, they should include not only the area of the water supply reservoir or reservoirs, but of all other water surfaces, and should also include 40 per cent. of the area of undrained swamps and 30 per cent. of the area of drained swamps.

By dividing the total area of water surfaces so determined by the number of square miles in the drainage area, the per cent. of water surfaces when the reservoirs are full is obtained.

The *available* capacity of the storage reservoir divided by the number of square miles in the whole drainage area gives the storage per square mile.

Several examples of the application of the tables and diagrams will be given. The first assumes a drainage area with only a small amount of storage, so that the storage reservoir is filled every spring and is liable to be exhausted by a drought of not more than six months' duration. It will be assumed that this source is located in Massachusetts, west of the Connecticut River, where the average elevation of the drainage area is 900 ft. above sea level. The assumptions and computations are as follows:

Assumed drainage area, including water surfaces	20 sq. miles.
Assumed area of water surfaces, including prescribed per cent. of swamps	0.25 sq. mile.
Assumed available storage capacity	520 mil. gal.
Water surfaces, $0.25 \div 20 =$	1.25 per cent.
Available storage per sq. mile of drainage area, $520 \div 20 =$	26 mil. gal.

The safe daily capacity of this source, as obtained from the capacity tables or diagrams of the different drainage areas, is as follows:

TABLE 24.

EXAMPLE OF USE OF CAPACITY TABLES — SMALL STORAGE.

Drainage Area.	Elevation above Sea Level. Feet.	Safe Capacity in Gallons per Day.	
		1 Sq. Mile.	20 Sq. Miles.
Cambridge, Stony Brook	180	200 000	4 000 000
Metropolitan Water Works: Sudbury River, 1908–1912	300	233 000	4 660 000
Waterbury, Naugatuck River	890	243 000	4 860 000
Hartford Reservoirs	460	258 000	5 160 000
Pawtucket, Abbott Run	150	266 000	5 320 000
New York Water Works: Croton River, 1879–1883	620	286 000	5 720 000
Metropolitan Water Works: Sudbury River, 1879–1884	300	297 000	5 940 000
Holyoke, Manhan River	950	337 000	6 740 000
New York Water Works: Esopus Creek	1 700	344 000	6 880 000
Worcester, Tatnuck Brook	950	383 000	7 660 000
Westfield, Tillotson Brook	990	387 000	7 740 000
Metropolitan Water Works: Wachusett Reservoir	750	404 000	8 080 000
Average		303 000	

In former years when estimates of the safe capacity of a source were based mainly upon the Sudbury River records of 1879–1883, computations like those above indicated gave a single result which might be accepted as the safe capacity of the proposed source, or might be modified for various reasons in accordance with the judgment of the engineer making the computations. Now that the records of many drainage areas are available, there is a wide variation in the results, especially when the amount of storage is small.

In the example given above, the amount of storage is so small that the reservoir would be sure to fill and overflow each spring, and if drawn upon to the extent of its safe capacity would reach its lowest point within six months of the time when the water ceased to run over the spillway.

For such short periods as this, the records of the run-off from different drainage areas are very varied, as the run-off at such times depends both upon the precipitation during the dry period and upon the amount of water stored in the interstices of the ground during the wet season which finds it way into the streams during the dry period.

One or two heavy showers or rains on any given drainage area during such a dry period materially affect the results, and although it is well known that the relative precipitation in a series of years upon different drainage areas is nearly uniform, there is no such uniformity during short periods.

Referring again to the example given above of a drainage area with small water surfaces, the capacity tables based upon drainage areas containing large water surfaces — like the Wachusett, Sudbury, Worcester, and Hartford sources — are not strictly applicable because of the unavoidable inaccuracy in making estimates of the evaporation from the large water surfaces for any given short period.

There is also another source of inaccuracy in such cases, — that the extremely dry period of six months or less, which really serves as a basis for determining the smaller figures of storage in the capacity tables, corresponds to a period when the large reservoirs are lowering rapidly, and some water is draining from the ground into the reservoir of which no account is taken in the records. The Wachusett Reservoir during the six months' period which served as a basis for the results in the foregoing example lowered 14 ft.

Reverting now to the table giving the safe capacity of the assumed source on the basis of the different capacity tables, it is well to omit on general principles the results based on Stony Brook, Sudbury River 1908–1912, and Esopus Creek, and on account of large water surfaces to omit also the results based on the Hartford Reservoirs, Tatnuck Brook, and Wachusett Reservoir. With these omissions, the safe capacity per square mile of drainage area ranges from 243 000 gal. daily on the basis of the Naugatuck River table to 387 000 gal. daily on the basis of the Tillotson Brook table. The average of all the results not excluded gives 303 000 gal. daily per sq. mile, equivalent to 6 060 000 gal. daily for

the whole drainage area. On the basis of the Naugatuck River, the safe capacity of this drainage area would be 4 860 000 gal. daily.

Whether, in a case like this, one should adopt 5 000 000 or 6 000 000 gal. daily as the safe capacity of the source will depend upon circumstances. If, as suggested in the statement immediately preceding the capacity tables, provision has been made for storage equivalent to the daily draft for a month, as a reserve which is not included in the available storage upon which the estimates of safe capacity have been based, there is more reason for adopting the larger figure than if this precaution had not been taken.

The yield of drainage areas for short periods is, as indicated by the results obtained, very variable, and as a small storage reservoir of this kind is drawn to a low level nearly every year and does not give much warning as to when it may be exhausted, it is desirable to be conservative and to adopt the lower estimate, unless it is known that there is an emergency supply which can quickly be made available.

The elevation above sea level does not seem to be an important factor when the storage is so small that it will tide over only a few dry months.

The second example assumes a drainage area situated in Massachusetts between the Wachusett and Abbott Run drainage areas, at a place where the average elevation of the assumed drainage area is 400 ft. above sea level. The assumptions and computations are as follows:

Assumed drainage area, including water surfaces.....	30 sq. miles.
Assumed area of water surfaces, including prescribed per cent. of swamps.....	1 sq. mile.
Assumed available storage capacity.....	3 900 mil. gal.
Water surfaces, 1÷30=.....	3.33 per cent.
Available storage per square mile of drainage area, 3 900÷30=.....	130 mil. gal.

The safe capacity of this source, as obtained from the capacity tables or diagrams of the different drainage areas, is as follows:

TABLE 25.

EXAMPLE OF USE OF CAPACITY TABLES — MEDIUM STORAGE.

Drainage Area.	Elevation above Sea Level. Feet.	Safe Capacity in Gallons per Day.	
		1 Sq. Mile.	30 Sq. Miles.
Cambridge, Stony Brook	180	547 000	16 410 000
Metropolitan Water Works: Sudbury River, 1908–1912	300	605 000	18 150 000
Pawtucket, Abbott Run	150	655 000	19 650 000
New York Water Works: Croton River, 1879–1883	620	689 000	20 670 000
Metropolitan Water Works: Sudbury River, 1879–1884	300	691 000	20 730 000
Waterbury, Naugatuck River	890	735 000	22 050 000
Holyoke, Manhan River	950	760 000	22 800 000
Hartford Reservoirs	460	760 000	22 800 000
Metropolitan Water Works: Wachusett Reservoir	750	769 000	23 070 000
Westfield, Tillotson Brook	990	793 000	23 790 000
Worcester, Tatnuck Brook	950	853 000	25 590 000
New York Water Works: Esopus Creek	1 700	915 000	27 450 000
Average		731 000	

In this case, after omitting the results based on Stony Brook, Sudbury River 1908–1912, and Esopus Creek, the computed capacities do not vary nearly as much as in the first example. One reason for this is that the assumed storage capacity is so large that the critical period upon which the computations of storage are based extends from the spring or early summer of 1910 to the autumn of 1911, and in so long a period the irregularities of precipitation are much less than during short periods.

As a matter of interest, one may average the quantities given in the table, with the exceptions noted, and obtain as a result a safe capacity per square mile of 745 000 gal. per day. This does not give the best results, however, because all of the drainage areas with the exception of Abbott Run have a greater elevation than the assumed drainage area, with a consequent higher precipitation and run-off.

Better results would be obtained in this case by using the results based upon the Abbott Run and Wachusett drainage areas, between which the assumed drainage area is located, and by giving due

weight to the relative elevations of the drainage areas. The Abbott Run drainage area is 150 ft. above sea level, and upon the basis of this source the safe capacity is 655 000 gal. daily per sq. mile. The Wachusett drainage area is 750 ft. above sea level, and upon the basis of this source the safe capacity is 769 000 gal. The assumed drainage area has an elevation of 400 ft. above sea level. By proportioning according to the relative elevations, the safe capacity of the assumed source is found to be 700 000 gal. daily per sq. mile, or 21 000 000 gal. daily for the whole drainage area. This appears to be a reasonable result.

The third example assumes the existence of a pond having a comparatively small drainage area, situated in Massachusetts at a place where the average elevation of the drainage area above sea level is 300 ft. The assumptions and computations are as follows:

Assumed drainage area, including water surfaces	2 sq. miles.
Assumed area of water surfaces, including prescribed per cent. of swamps	180 acres = 0.282 sq. mile.
Assumed available storage capacity	600 mil. gal.
Water surfaces, 0.282 ÷ 2 =	14.1 per cent.
Available storage per square mile of drainage area, 600 ÷ 2 =	300 mil. gal.

The safe daily capacity of this source, as obtained from the capacity tables or diagrams of the different drainage areas, is as follows:

TABLE 26.

EXAMPLE OF USE OF CAPACITY TABLES — LARGE STORAGE.

Drainage Area.	Elevation above Sea Level. Feet.	Safe Capacity in Gallons per Day.	
		1 Sq. Mile.	2 Sq. Miles.
Cambridge, Stony Brook	180	611 000	1 220 000
Metropolitan Water Works: Sudbury River, 1908–1912	300	683 000	1 370 000
Pawtucket, Abbott Run	150	768 000	1 540 000
Metropolitan Water Works: Sudbury River, 1879–1884	300	803 000	1 610 000
Wachusett Reservoir	750	881 000	1 760 000
New York Water Works: Croton River, 1879–1883	620	905 000	1 810 000
Hartford Reservoirs	460	900 000	1 800 000
Waterbury, Naugatuck River	890	954 000	1 910 000
Westfield, Tillotson Brook	990	960 000	1 920 000
Worcester, Tatnuck Brook	950	979 000	1 960 000
Holyoke, Manhan River	950	1 007 000	2 010 000
New York Water Works: Esopus Creek	1 700	1 248 000	2 500 000
Average		892 000	

The average, after omitting the records of Stony Brook, Sudbury River 1908–1912, and Esopus Creek, is 906 000 gal. per day per sq. mile, but the low elevation of the assumed drainage area would make the Abbott Run basis to a large extent controlling, and 800 000 gal. per sq. mile, equivalent to 1 600 000 gal. per day for the whole drainage area, would be a more reasonable quantity to adopt as the safe capacity of the source.

With so large a storage capacity per square mile as is assumed in this case, it would require three years or more to exhaust the reservoir. An extremely dry period, such as has recently occurred, is not likely to occur except after long intervals, and under ordinary conditions such a source would supply 1 800 000 or 1 900 000 gal. of water per day. It is an advantage of such a large amount of storage that a town may continue to use such a source until its water consumption is considerably above the so-called safe capacity of the source, because with so large a quantity of storage there is time to provide an additional supply after the source gives indication that it is insufficient.

TABLE 27.

EXAMPLE OF USE OF CAPACITY TABLES FOR OBTAINING SAFE CAPACITY OF WACHUSETT SUPPLY.

Drainage area, including water surfaces		118.19 sq. miles.
Water surfaces, exclusive of swamps	8.59 sq. miles.	
40 per cent. of 2.91 square miles of undrained swamps	1.16 sq. miles.	
30 per cent. of 0.68 square mile of drained swamps	0.20 sq. mile.	
Total area reckoned as water surfaces		9.95 sq. miles.
Water surfaces, 9.95 ÷ 118.19		8.42 per cent.
Total storage, Wachusett Reservoir (elevation 395.0)		64 968 mil. gal.
Storage below elevation 330, called unavailable		9 415 mil. gal.
Available storage		55 553 mil. gal.
Available storage per square mile, 55 553 ÷ 118.19		470 mil. gal.
Safe daily draft per square mile, obtained by interpolation from table for Wachusett drainage area		1 015 000 gal.
Total safe daily capacity, 1 015 000 × 118.19		120 000 000 gal.

The fourth example relates to the safe capacity of the Wachusett supply as it existed before the water from a part of the drainage area was diverted for the water supply of the city of Worcester. This supply was very highly developed for the purpose of improving the quality of the water and of providing surplus storage which could be utilized in connection with future additions to the supply.

Although the above table shows that a daily draft of a little more than 1 000 000 gal. per sq. mile could be obtained from the Wachusett drainage area as it is now developed, it is found, by referring to the detailed records, not only that the reservoir would not have filled with such a draft after June 1, 1908, but that it would have been at a lower level at the end of the dry period of each successive year, and would just have exhausted the available storage in the reservoir at the end of January, 1914. At the end of July, 1914, the amount of water stored would have been 2 624 mil. gal. more than at the corresponding date in 1913. What the future condition of the reservoir would be, with the assumed draft, cannot be foretold. A continuation of dry years would make still further demand upon it, while with average or wet years the water would rise.

COMPOSITE CAPACITY DIAGRAM.

It will be noted by reference to the capacity diagrams that they are composed of straight lines instead of curves, and similarly, in the capacity tables there will frequently be found constant differences between successive terms in a column. For instance, in Table 15, relating to the Wachusett drainage area, in the column headed 0 per cent., there is a constant difference of 9.2 between successive figures from 23.2 to 69.2 mil. gal. of required storage. The reason for this is that the yield during a certain six months was the critical period upon which all of the figures of storage between these limits were based.

The straight lines and constant differences mentioned are the result of basing the diagrams and tables on actual records of yield, and they consequently represent only approximately the general law affecting the relation between the amount of storage and the

safe daily capacity of the source. The general law is that as the amount of storage is increased, a larger increment of storage is required for a given increment in the safe capacity of the source; that is, by the general law the difference between successive figures of required storage in the tables should always be increasing instead of being constant in some parts of the tables.

As an illustration, reference is made to the first and second columns of Table 15, where the required storage corresponding to an increase of 50 000 gal. in the daily supply or safe capacity is as follows:

Increase in Daily Supply. Gallons.	Corresponding Increment in Required Storage. Million Gallons.
200 000 to 250 000	2.8
400 000 to 450 000	9.2
600 000 to 650 000	9.2
800 000 to 850 000	24.0
1 000 000 to 1 050 000	104.0

COMPOSITE DIAGRAM

Storage Capacity Required to Supply Various Quantities of Water Daily from One Square Mile of Drainage Area Containing Various Percentages of Water Surface

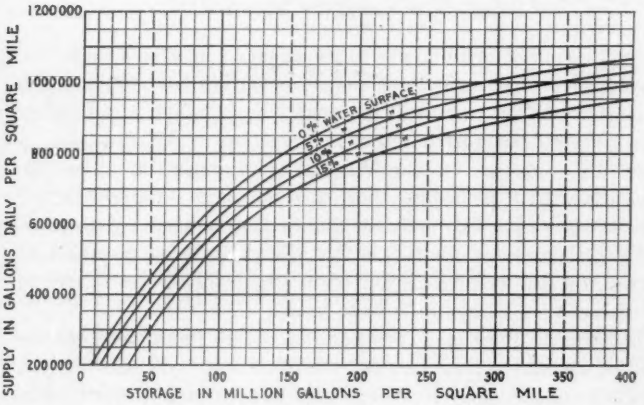


FIG. 7.

The illustration shows clearly that a very much larger quantity of storage is required to furnish an increment of 50 000 gal. in the daily supply when the supply, and consequently the storage, is large than when it is small, but it also shows what is not in accordance with the general law — that 9.2 mil. gal. storage is as effective in increasing the daily supply when it is 600 000 gal. as when it is 400 000 gal.

Notwithstanding this failure of the diagrams and tables to comply with the general law here pointed out, it has been thought best to keep them in the form in which they were computed, so that when used they will give the results which would obtain if there were a recurrence of the identical dry periods on which the tables and diagrams were based.

For some studies, however, it will be more useful to have a diagram which will represent more closely the general law, and a composite diagram (Fig. 7) is therefore presented, which is based upon the following diagrams; Abbott Run; Sudbury,

TABLE 28.

TABLE SHOWING INCREMENT IN STORAGE CAPACITY CORRESPONDING TO INCREMENT IN DAILY SUPPLY FROM ONE SQUARE MILE OF DRAINAGE AREA CONTAINING VARIOUS PERCENTAGES OF WATER SURFACE BASED UPON COMPOSITE DIAGRAM.

Increment in Daily Supply. Gallons.	Increment in Required Storage. Million Gallons.			
	0 Per Cent.	5 Per Cent.	10 Per Cent.	15 Per Cent.
200 000 to 250 000	7.2	7.2	7.6	7.5
250 000 to 300 000	7.8	7.9	8.2	8.1
300 000 to 350 000	8.4	8.6	8.8	8.7
350 000 to 400 000	9.0	9.3	9.4	9.4
400 000 to 450 000	9.6	10.0	10.0	10.1
450 000 to 500 000	10.2	10.7	10.7	11.0
500 000 to 550 000	10.9	11.5	11.9	12.4
550 000 to 600 000	11.7	12.7	13.6	14.6
600 000 to 650 000	12.9	14.3	15.8	17.6
650 000 to 700 000	14.4	16.3	18.5	21.6
700 000 to 750 000	16.3	18.7	22.0	26.6
750 000 to 800 000	18.8	21.7	26.0	33.0
800 000 to 850 000	22.6	26.5	33.0	43.0
850 000 to 900 000	28.8	35.0	45.0	57.0
900 000 to 950 000	38.7	49.5	62.0	75.0
950 000 to 1 000 000	53.6	71.0	83.0	
1 000 000 to 1 050 000	74.8	103.0		

1879–1884; Wachusett; Manhan River; Tillotson Brook; Naugatuck River; Croton, 1879–1883; Croton, 1908–1913.

The preceding table is derived from the composite diagram, and shows the increment of required storage for each increment of 50 000 gal. daily of daily supply.

EFFECT OF A CONSTANT DAILY DRAFT FROM WACHUSETT RESERVOIR EQUAL TO SAFE CAPACITY OF SOURCE, 1897–1914.

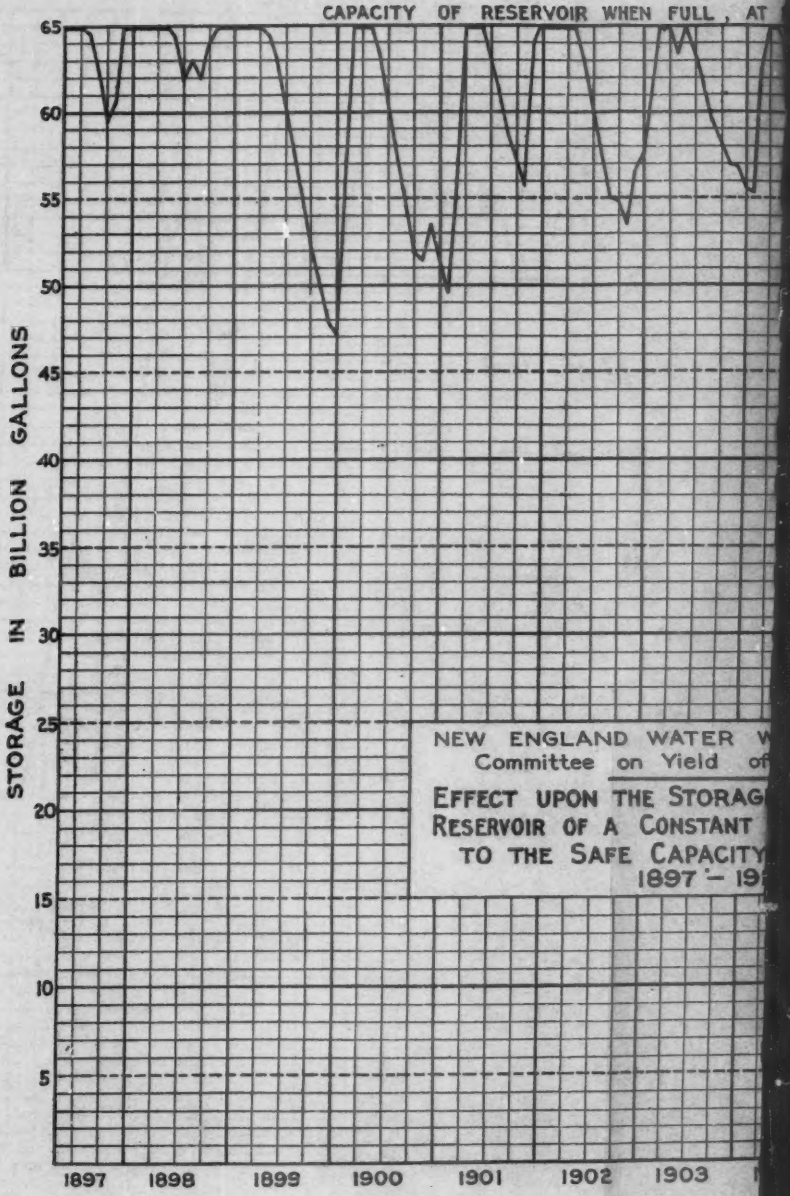
The accompanying diagram (Plate XII) shows graphically what the effect upon the Wachusett Reservoir would have been had it been filled in May, 1897, and had there been drawn from it a constant daily quantity of water which would have exhausted the available storage in January, 1914. The diagram shows that from 1897 to 1908, inclusive, the reservoir would have filled and overflowed in all but three years, and that during this period it would not have been drawn more than 15 ft. below the high water level, or to such an extent as to reduce the amount of stored water to less than 68 per cent. of the total available storage.

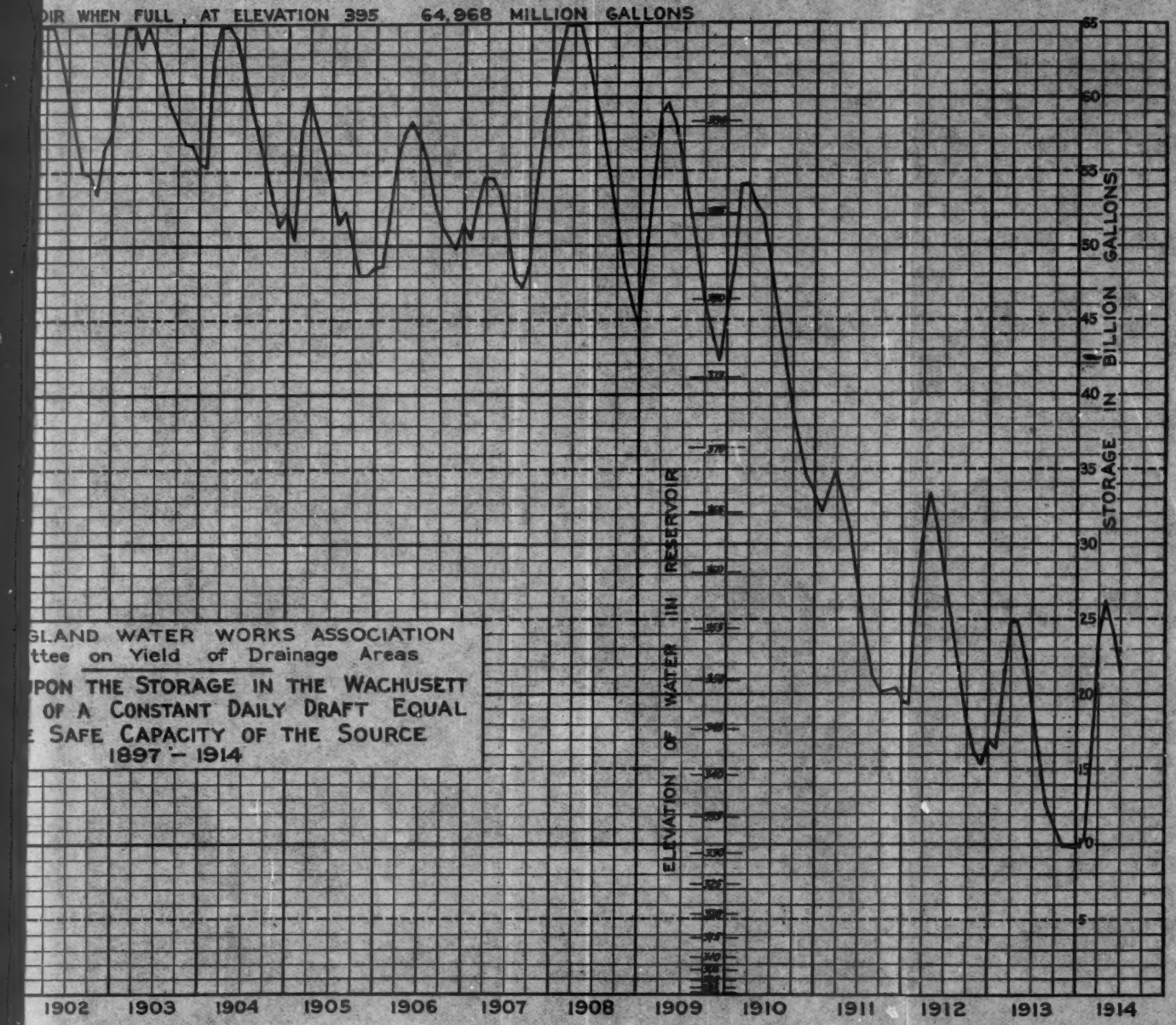
Beginning in June, 1908, however, the reservoir would have reached a lower point each successive year, as already stated, reaching the lowest point up to the present time in January, 1914.

ADVANTAGE OF LARGE STORAGE CAPACITY.

A storage reservoir which is very large in proportion to its drainage area has certain advantages to which further attention will be called. One of these is that it cannot be exhausted in one or two dry years, but, depending upon the amount of development, three, four, five, or six years may be required to exhaust it.

One may determine from the tables the safe capacity of a source with such a reservoir, but it does not follow that it will be necessary to obtain an additional supply at precisely the time when the water consumption reaches such capacity. The safe capacity is based upon the records of the driest period, and under more usual conditions of average or wet years the source would continue to furnish a quantity considerably in excess of the safe capacity, and fill each spring. After the reservoir had failed to fill for a year or


CAPACITY OF RESERVOIR WHEN FULL, AT
STORAGE IN BILLION GALLONS
65
60
55
50
45
40
35
30
25
20
15
10
5
1897
1898
1899
1900
1901
1902
1903
NEW ENGLAND WATER W
Committee on Yield of
EFFECT UPON THE STORAG
RESERVOIR OF A CONSTANT
TO THE SAFE CAPACITY
1897 – 19


DIR WHEN FULL, AT ELEVATION 395 64,968 MILLION GALLONS
GLAND WATER WORKS ASSOCIATION
ttee on Yield of Drainage Areas
PON THE STORAGE IN THE WACHUSETT
OF A CONSTANT DAILY DRAFT EQUAL
SAFE CAPACITY OF THE SOURCE
1897 – 1914
ELEVATION OF WATER IN RESERVOIR
STORAGE IN BILLION GALLONS
65
60
55
50
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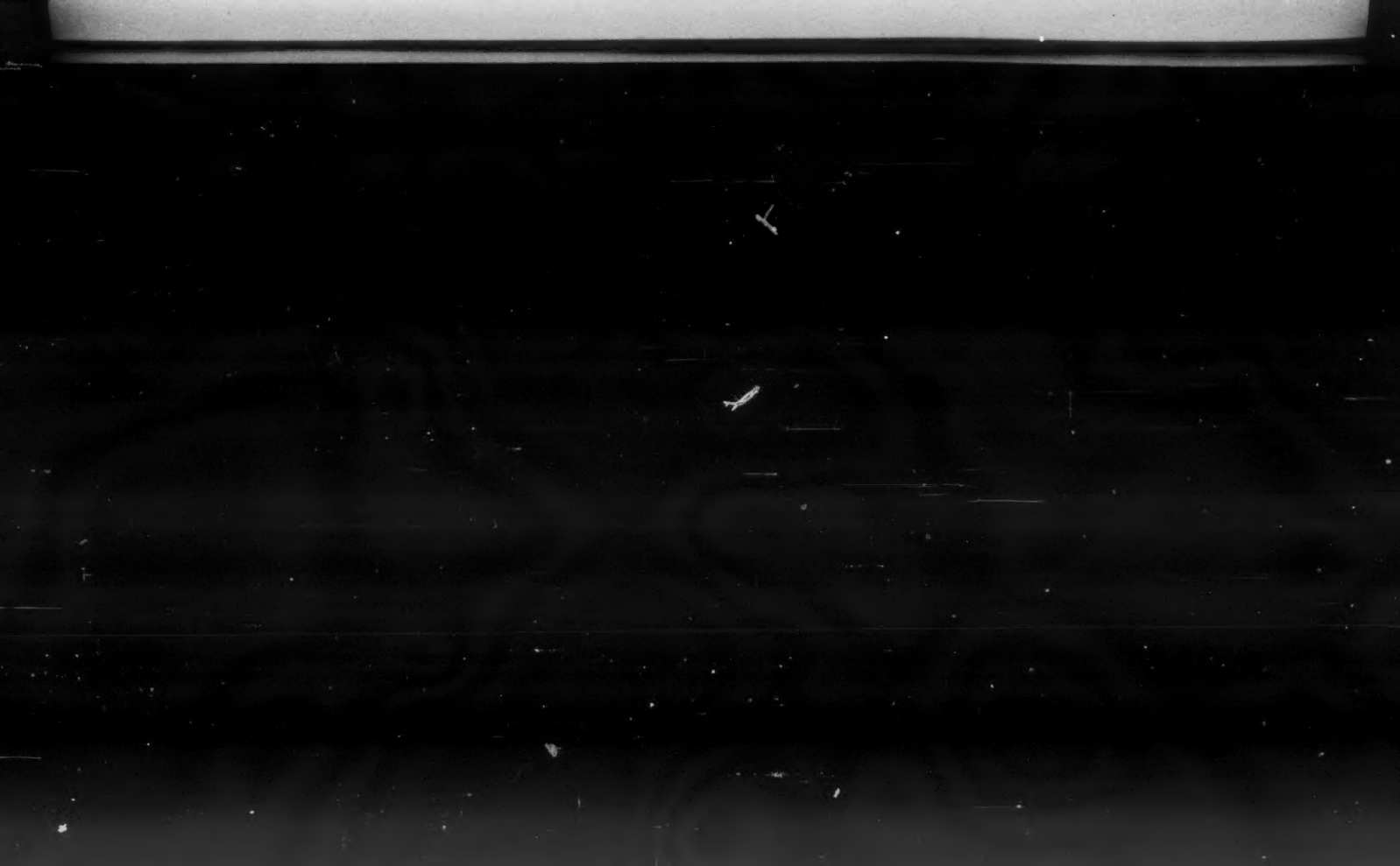
1911
1912
1913
1914



two, there might still be time before it could be exhausted to obtain an additional supply.

This distinction between a small storage capacity, sufficient to tide over, say, from four to six months when the flow of the streams is very low, and a large storage capacity, such as is above described, should be kept always in mind. The small storage reservoir would be drawn down to a considerable extent nearly every year, and its exhaustion in a very dry year would come without much warning. Under such circumstances, the safe capacity should be reckoned on a very conservative basis, unless it is feasible to obtain an emergency supply from some source without delay. With the larger storage reservoir there is more time available for obtaining an additional supply, so that the safe capacity, where it is possible to obtain such a supply without too much delay, may be reckoned on a less conservative basis.

A large storage reservoir is especially advantageous for sanitary reasons.

MINIMUM FLOW OF STREAMS.

As already stated, one item of information asked for from those in charge of stream gagings was the daily flow of streams during the driest periods of one, two, and three months included in the records. Such records are at times useful in determining the capacity of supplies taken from streams without any considerable amount of storage, and are also useful in connection with studies of water power. The results obtained from different drainage areas are necessarily variable.

Records of this kind have value only when deduced from drainage areas having small water surfaces, because the evaporation from large water surfaces in very dry periods frequently exceeds the yield of the drainage area, and estimates of the amount of evaporation during any short period are likely to be considerably in error.

It takes comparatively little storage to increase to a considerable extent the minimum flow of a stream, and in the tables which follow the records of run-off which have been corrected for water drawn from storage have been kept separate from the records of

TABLE 29. — TABLE GIVING MINIMUM FLOW OF DRAINAGE AREAS IN GALLONS DAILY PER SQUARE MILE OF LAND SURFACE, FOR PERIODS RANGING FROM ONE WEEK TO THREE MONTHS.

Correction Made for Water Drawn from Storage.

DRAINAGE AREA.		Year.	PERIOD.				
Name.	Square Miles.		One Week.	Two Weeks.	One Month.	Two Months.	Three Months.
Holyoke, Manhan River	13.0	1900	51 000	56 000	78 000	123 000	127 000
Westfield, Tillotson Brook*	5.84	1910	130 000	137 000	144 000	176 000	180 000
Pawtucket, Abbott Run	26.19	1910	———	———	54 000	71 000	103 000
Waterbury, West Branch of Naugatuck River	17.80	1912	———	———	36 000	45 000	43 000
New York Water Works:							
Esopus Creek	239.0	1908	52 000	57 000	66 000	———	———
		1909	———	———	———	———	143 000
		1913	———	———	———	115 000	———
Rondout Creek	102.0	1908	38 000	61 000	79 000	95 000	———
		1909	———	———	———	———	136 000
Schoharie Creek	236.0	1908	19 000	20 000	31 000	63 000	———
		1909	———	———	———	———	77 000

TABLE 30. — TABLE GIVING MINIMUM FLOW OF DRAINAGE AREAS IN GALLONS DAILY PER SQUARE MILE, FOR PERIODS RANGING FROM ONE WEEK TO THREE MONTHS.

No Correction made for Water Drawn from Storage.

DRAINAGE AREA.		Year.	PERIOD.				
Name.	Square Miles.		One Week.	Two Weeks.	One Month.	Two Months.	Three Months.
Connecticut River at Orford, N. H.	3 300	1908	95 000	101 000	118 000	143 000	151 000
Connecticut River at Sunderland, Mass.,	7 700	1908	128 000	135 000	143 000	150 000	160 000
Merrimack River at Lawrence, Mass.	4 452	1911	112 000	145 000	169 000	186 000	205 000

* See note on page 471.

the streams where the flow has been augmented to some extent by storage.

The records of the recent dry period do not necessarily include the driest months which have occurred, as there are sometimes some extremely dry months during years which, taken as a whole, are not extremely dry. For instance, the minimum flow of the Manhan River for periods of one, two, and three months occurred in July, August, and September, 1900, and not during the recent dry period.

Little dependence can be placed upon estimates of the safe capacity of small streams not supplemented with storage water.

SUMMARY.

1. REASON FOR REPORT. The committee was appointed early in 1911 on account of the low flow of the streams during the years 1908, 1909, and 1910. The year 1911 proved to be even drier than the preceding years, and 1912 and 1913 nearly as dry.

2. RECENT DRY PERIOD THE DRIEST SINCE STREAMS HAVE BEEN MEASURED. Until the recent dry period, that from 1879 to 1884 was the driest on record. The recent period has been drier in the greater part of New England, but not as dry in eastern New York. Judging from rainfall records, still drier periods occurred prior to 1850.

3. YIELD OF DRAINAGE AREAS DEFINED. In the case of a drainage area on which there are no storage reservoirs or ponds, the yield of a drainage area means the quantity of water flowing in the stream at the lower end of the area.

When a storage reservoir has been built upon the stream and the discharge is measured at the dam, the yield of a drainage area, as water works records are usually kept, means the quantity of water discharged at the dam, corrected by adding or subtracting, respectively, the quantity of water drawn from or added to storage. It is therefore approximately the natural flow of the stream, but not exactly, because there is a loss of water by evaporation from the surface of the reservoir, which is not measured.

In the case of rivers like the Merrimack and Connecticut, where it is not feasible to make corrections for the amount of water

drawn from or added to storage, the yield of a drainage area, as usually recorded, does not mean the natural flow of the stream, but the natural flow increased by water drawn from storage in the dry season and decreased by the water added to storage when the reservoirs are filling.

When there is a reservoir at the lower end of a drainage area, there is sometimes added an unmeasured loss due to leakage past the dam, and there may be storage of which no account is taken, as, for instance, that in the interstices of the ground around the reservoirs and in small reservoirs not under water works control.

4. Evaporation from Water Surfaces Important. When there are large water surfaces the evaporation is an important item, and the yield of one drainage area should not be deduced from that of another without taking account of this element.

5. Yield of Water Surfaces. The yield of a water surface is the difference between the precipitation upon and the evaporation from such surface, multiplied by its area. In the summer, when the evaporation is high, the evaporation is nearly always greater than the precipitation, while in the cold weather the reverse is true.

6. Yield of Land Surfaces. The measurements of the yield of a drainage area necessarily include the combined yield of land and water surfaces, but it is feasible to estimate the yield of water surfaces with a fair degree of accuracy, and when such yield is deducted from the total yield of a drainage area, the remainder is the yield of the land surface. A much better comparison of the yield of different drainage areas can be made when the yield of land surfaces only is used.

7. Swamps. Swamps are generally covered with water during a part of the year and are damp at other times, so that as regards evaporation they are intermediate between water surfaces and ordinary land surfaces. It has been assumed, for the purposes of this report, that 40 per cent. of the area of undrained swamps and 30 per cent. of the area of drained swamps should be classed as water surface, and the remainder as land surface.

8. Relation of Precipitation to Yield. The water flowing from a drainage area has its origin, under nearly all circumstances, in the precipitation upon the area, and that part of the precipitation which is not evaporated, except for the small quantity of water absorbed by vegetation, finds its way into the streams. The precipitation in this section of the country is reasonably uniform throughout the year, but the evaporation which increases with the temperature varies greatly, being about six times as much in midsummer as in winter. Hence, a very much larger part of the precipitation is lost by evaporation from land surfaces in the warm than in the cold months. During the four years, 1908–1911, the percentage of the precipitation not evaporated, and consequently finding its way into the streams, was as follows:

	Per Cent.
December to April, inclusive	70.3
May, June, and November	46.0
July to October, inclusive	15.9

In years when the precipitation is large the percentage running off is greater than in years when it is small, because the evaporation from land surfaces does not increase at the same rate as the precipitation. As a result of many comparisons it was found that when the precipitation increased from 39.29 to 56.29 in. annually the percentage running off increased from 43.1 to 53.3. To express the relation in another way, 77 per cent. of the above increase in precipitation was represented by the run-off in the streams.

The above figures are based on the maximum and minimum precipitation on several drainage areas during a long series of years. If comparisons were to be made between the low and high precipitation during a series of comparatively dry years, as, for instance, between annual precipitations of 35 and 40 in., or 40 and 45 in., less than 77 per cent. of the difference in precipitation would be represented by the run-off. It has been assumed somewhat arbitrarily that in these cases the percentages would be, respectively, 65 and 70.

9. Elevation of Drainage Area an Important Factor. Other things being equal, the precipitation and consequently the

yield of a drainage area increases with the elevation above the sea. The lowest records of yield received are those of low-lying drainage areas near the coast, and the highest yield recorded is of drainage areas at a high elevation in the Catskill Mountains. Observations on the top of Mt. Washington from 1876 to 1886 gave an average precipitation of 90.13 in., while the averages for the Sudbury and Cochituate watersheds for the same period were, respectively, 44.02 and 42.59 in.

10. Capacity Tables and Diagrams. The principal aim of the report is to furnish tables and diagrams based upon trustworthy information to facilitate computations of the safe capacity of sources of water supply. In order to use these tables, it is necessary to have:

1. The drainage area in square miles.
2. The area of water surfaces when the reservoirs are full, in square miles.
3. The *available* capacity of the storage reservoir, in million gallons.

In computing the tables, the area of water surfaces in most instances included 40 per cent. of the area of undrained swamps and 30 per cent. of the area of drained swamps, and in applying the tables in such cases it is desirable that the area of water surfaces should include these percentages of the swamps on the drainage areas under consideration, if the most accurate results are desired.

The tables give results which vary widely, but they show what the safe capacity of proposed sources would be on the basis of the conditions which actually existed upon the drainage areas upon which the tables were based. With such wide differences in results, good judgment and a complete knowledge of the facts upon which the tables are based are necessary in order to determine intelligently the probable safe capacity of any given source.

11. Minimum Flow of Streams. Tables on page 466 give the minimum flow of streams for short periods of from one week to three months. The results vary widely and indicate that one

should be very conservative in fixing the safe capacity of a source where there is little or no storage capacity.

Respectfully presented,

FREDERIC P. STEARNS, *Chairman*,
H. K. BARROWS, *Secretary*,
GEORGE A. CARPENTER,
CHARLES E. CHANDLER,
X. H. GOODNOUGH,
RICHARD A. HALE,
ELBERT E. LOCHRIDGE,
LEONARD METCALF,
ARTHUR T. SAFFORD,
JAMES L. TIGHE,

Committee.

NOTE: Since writing the above report a very low stream flow occurred in some parts of New England in the autumn of 1914. The minimum flow of Tillotson Brook, Westfield, during this time has been much lower than the previous results recorded in the table on page 442, thus confirming the views expressed in the last of the above paragraphs as to the necessity of being conservative in fixing the safe capacity of a source where there is little or no storage capacity.

The new Tillotson Brook records are as follows:

	Gals. Daily per Sq. Mile.
One week, September 18–24, 1914	86 000
Two weeks, September 11–24, 1914	94 000
One month, September, 1914	111 000
Two months, August–September, 1914	140 000
Three months, August, September, October, 1914	152 000

Appendix No. 1.

DETAILED STATISTICS OF THE YIELD OF DRAINAGE AREAS.

Maine.
- Sebago Lake.

New Hampshire.
- Connecticut River at Orford.

Massachusetts.
- Connecticut River at Sunderland.
- Deerfield River at Shelburne Falls.
- Merrimack River at Lawrence.
- Cambridge Water Works, Stony Brook.
- Holyoke Water Works, Manhan River.
- Metropolitan Water Works:
  - Wachusett Reservoir.
  - Sudbury River.
  - Lake Cochituate.
- Springfield Water Works, Westfield Little River.
- Westfield Water Works, Tillotson Brook.
- Worcester Water Works, Tatnuck Brook.

Rhode Island.
- Pawtucket Water Works, Abbott Run.

Connecticut.
- Hartford Water Works, Hartford Reservoirs.
- Norwich Water Works, Fairview and Meadow brooks.
- Waterbury Water Works, West Branch of Naugatuck River.

New York.
- New York Water Works:
  - Croton River.
  - Esopus Creek.
  - Rondout Creek.
  - Schoharie Creek.

SEBAGO LAKE, MAINE.

Information furnished by S. D. Warren Co.
Yield measured at the outlet of lake, 1908–1911.

Drainage area, including water surfaces	436.0 sq. miles
Area of water surfaces	71.6 sq. miles
Area of land surface	364.4 sq. miles

The area of Sebago Lake is 45.6 sq. miles, and of thirty-eight other lakes and ponds 24.4 sq. miles.

Estimated area of undrained swamps, 4 sq. miles.

Correction was made for the effect of storage in Sebago Lake in all years and in the years 1909, 1910, and 1911, a further correction was made for the effect of storage in other lakes, but gage heights were taken only in one additional lake, so that the corrections for storage are uncertain.

The water from Sebago Lake is used for supplying the Portland water district, and due account has been taken of the water so used and of leakage at the outlet of the lake.

The whole drainage area is mountainous and hilly and the soil is gravelly and sandy; about 80 per cent. of the whole area is forested.

The elevation of Sebago Lake is 262 ft. above sea level. Most of the flow is measured through turbines which were tested at the Holyoke Testing Flume and again after installation, the quantity discharged in the latter test being carefully measured by current meters. The results of the tests differed 2 per cent.

The gagings do not conform with others as to the distribution of flow among the different months of the year, which appears to be due to the incompleteness of the records of the gain or loss of storage at some of the large lakes. The main value of the gagings, therefore, lies in results for a year or series of years and not for shorter periods.

The rain gages used are Standard United States rain gages located near the ground.

SEBAGO LAKE, MAINE, 1908.

Yield of lake at outlet. Total drainage area, 436 sq. miles. Area of land surface, 364.4 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	12 704	2 125	14 829	1.125	1.74	1.099	1.70	2.66	2.007	75.4	1.959	73.7
Feb.	12 135	3 912	16 047	1.148	1.78	1.273	1.97	4.19	1.915	45.7	2.124	50.8
Mar.	14 648	560	15 208	1.297	2.01	1.127	1.74	2.15	2.312	107.6	2.009	93.4
Apr.	25 316	324	25 640	2.316	3.58	1.961	3.03	2.53	3.999	158.0	3.393	134.1
May	18 047	2 986	21 033	1.598	2.47	1.560	2.41	5.00	2.843	56.9	2.785	55.4
June	14 987	−3 148	11 839	1.371	2.12	0.906	1.40	0.77	2.366	307.3	1.569	203.9
July	3 109	−1 953	1 156	0.275	0.43	0.086	0.13	3.43	0.491	14.3	0.153	4.5
Aug.	10 710	−2 488	8 222	0.948	1.47	0.609	0.94	3.20	1.692	52.9	1.085	33.9
Sept.	1 225	−3 061	−1 836	0.112	0.17	−0.143	−0.22	0.86	0.193	22.4	−0.243	−28.3
Oct.	1 760	1 595	3 355	0.156	0.24	0.249	0.38	3.58	0.278	7.8	0.444	12.4
Nov.	2 122	162	2 284	0.194	0.30	0.173	0.27	1.43	0.335	23.4	0.302	21.1
Dec.	4 634	3 185	7 819	0.410	0.63	0.581	0.90	3.44	0.732	21.3	1.034	30.1
Year	121 397	4 199	125 596	0.912	1.41	0.790	1.22	33.24	19.163	57.6	16.614	49.9

SEBAGO LAKE, MAINE, 1909.

Jan.	2 489	5 853	8 342	0.220	0.34	0.617	0.95	5.66	0.392	6.9	1.101	19.5
Feb.	9 151	5 435	14 586	0.897	1.39	1.197	1.85	5.42	1.445	26.7	1.927	35.6
Mar.	21 133	2 613	23 746	1.871	2.89	1.759	2.72	3.80	3.337	87.8	3.140	82.6
Apr.	59 348	1 630	60 978	5.429	8.40	4.669	7.22	3.70	9.371	253.3	8.071	218.1
May	20 316	871	21 187	1.798	2.78	1.570	2.43	3.30	3.208	97.0	2.801	85.0
June	11 875	−1 170	10 705	1.086	1.68	0.819	1.27	2.36	1.875	79.4	1.419	60.1
July	5 998	−3 148	2 850	0.531	0.82	0.210	0.33	2.47	0.947	38.3	0.374	15.1
Aug.	5 376	−4 242	1 134	0.475	0.74	0.085	0.13	1.79	0.848	47.4	0.150	8.4
Sept.	7 914	−2 613	5 301	0.723	1.12	0.404	0.63	5.42	1.250	23.1	0.702	13.0
Oct.	3 139	−1 219	1 920	0.278	0.43	0.143	0.22	1.32	0.496	37.6	0.254	19.2
Nov.	−1 310	1 605	295	−0.120	−0.19	0.021	0.03	2.59	−0.207	−8.0	0.039	1.5
Dec.	−1 160	2 551	1 391	−0.103	−0.16	0.102	0.16	2.93	−0.183	−6.2	0.184	6.3
Year	144 269	8 166	152 435	1.084	1.68	0.966	1.50	40.76	22.779	55.9	20.162	49.5

SEBAGO LAKE, MAINE, 1910.

Jan.	8 495	3 150	11 645	0.752	1.16	0.862	1.33	3.49	1.341	38.4	1.538	44.1
Feb.	3 514	4 449	7 963	0.344	0.53	0.652	1.01	4.63	0.555	12.0	1.049	22.7
Mar.	29 488	−88	29 400	2.610	4.04	2.179	3.37	1.63	4.654	285.5	3.889	238.3
Apr.	29 843	2 613	32 456	2.730	4.22	2.485	3.84	4.49	4.714	105.0	4.299	95.8
May	16 853	−659	16 194	1.492	2.31	1.200	1.86	2.07	2.662	128.5	2.141	103.5
June	11 147	−75	11 072	1.020	1.57	0.847	1.31	3.24	1.760	54.3	1.467	45.3
July	3 393	−4 065	−672	0.300	0.46	−0.050	−0.08	1.80	0.536	29.8	−0.089	−4.9
Aug.	5 750	−1 070	4 680	0.509	0.79	0.347	0.54	4.34	0.908	20.9	0.619	14.3
Sept.	3 737	−162	3 575	0.342	0.53	0.272	0.42	3.19	0.590	18.5	0.473	14.8
Oct.	−822	−25	−847	0.075	0.11	−0.063	−0.10	2.28	−0.130	−5.7	−0.112	−4.9
Nov.	−2 816	1 244	−1 572	−0.258	−0.40	−0.121	−0.19	2.30	−0.445	−19.4	−0.208	−9.0
Dec.	−2 175	3 173	998	−0.193	−0.30	0.075	0.12	3.43	−0.344	−10.0	0.132	3.8
Year	106 407	8 485	114 892	0.810	1.25	0.724	1.12	36.89	16.801	45.6	15.198	41.2

SEBAGO LAKE, MAINE, 1911.

Jan.	2 548	2 031	4 579	0.226	0.35	0.339	0.52	2.59	0.402	15.5	0.605	23.4
Feb.	5 564	2 699	8 263	0.545	0.84	0.678	1.05	3.22	0.879	27.3	1.091	33.9
Mar.	5 257	3 733	8 990	0.465	0.72	0.666	1.03	4.70	0.830	17.7	1.189	25.3
Apr.	39 805	−1 157	38 648	3.641	5.63	2.958	4.57	1.46	6.283	430.5	5.113	350.0
May	12 565	−1 925	10 640	1.112	1.72	0.788	1.22	1.05	1.985	189.0	1.406	133.9
June	11 018	−348	10 670	1.008	1.56	0.509	0.79	3.02	1.739	57.6	1.413	46.8
July	2 480	−523	1 957	0.220	0.32	0.145	0.22	4.58	0.392	8.6	0.259	5.7
Aug.	3 681	−3 061	620	0.326	0.50	0.046	0.07	2.74	0.582	21.2	0.082	3.0
Sept.	857	859	1 716	0.078	0.12	0.131	0.20	4.01	0.135	3.4	0.227	5.7
Oct.	2 925	75	3 000	0.259	0.40	0.222	0.34	2.36	0.462	19.5	0.397	16.8
Nov.	2 373	2 837	5 210	0.217	0.34	0.399	0.62	3.58	0.375	10.5	0.691	19.3
Dec.	−3 155	3 419	264	−0.279	−0.43	0.019	0.03	3.63	−0.498	−13.7	0.035	1.0
Year	85 918	8 639	94 557	0.652	1.01	0.575	0.89	36.94	13.566	36.7	12.508	33.9

CONNECTICUT RIVER AT ORFORD, N. H.

Discharge measurements made by United States Geological Survey, 1908–1911.

Drainage area, including water surfaces	3 300 sq. miles
Estimated area of water surfaces	20 sq. miles
Area of land surface	3 280 sq. miles

Area of swamps, unknown.

No correction is made for evaporation or storage.

The drainage area located in New Hampshire and Vermont has generally steep slopes, which are for the most part forested, although there are considerable areas under cultivation. A considerable portion of the White Mountain district in New Hampshire is included, as well as the eastern slopes of the Green Mountains in Vermont.

The elevation above the sea ranges from 380 to 6 279 ft.

The discharge is based upon measurements of the elevation of the surface of the water in the river, usually taken daily, and the use of a rating curve based upon occasional current meter measurements. The discharge during the frozen season is affected by ice, which changes the relation of the gaging heights to the discharge. The monthly discharge during low water periods is probably subject to errors of from 5 to 10 per cent., and during the frozen season may occasionally be in error 15 to 25 per cent.

Although it cannot be claimed that the gagings are sufficiently exact to be wholly trustworthy, they are given in connection with other measurements of the Connecticut River and of the Deerfield River as an indication of the larger yield of drainage areas having a high elevation.

The precipitation upon this drainage area is deduced from United States Weather Bureau records at the following stations: Bloomfield, Vt.; St. Johnsbury, Vt.; Chelsea, Vt.; Bethlehem, N. H.

The mean precipitation deduced from these records is probably considerably too low, as none of the stations are located in the regions of high elevation, where the precipitation is the greatest. This probably accounts in part for the high percentage of rainfall running off, as given in the tables.

CONNECTICUT RIVER AT ORFORD, N. H., 1908.
Total drainage area, 3 300 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.
January	4 410	0.87	1.34	1.80	1.55	86.2
February	4 830	0.94	1.46	3.08	1.57	51.0
March	7 580	1.49	2.30	1.97	2.66	135.0
April	12 800	2.51	3.88	2.38	4.33	182.0
May	12 700	2.49	3.85	3.39	4.44	131.0
June	4 450	0.87	1.35	3.51	1.51	43.0
July	1 540	0.30	0.47	3.28	0.54	16.5
August	1 690	0.33	0.51	4.05	0.59	14.6
September	627	0.12	0.19	0.97	0.21	21.6
October	747	0.15	0.23	1.76	0.26	14.8
November	1 040	0.21	0.32	1.55	0.35	22.6
December	1 200	0.23	0.36	2.54	0.42	16.5
The Year	4 470	0.88	1.36	30.28	18.43	60.8

CONNECTICUT RIVER AT ORFORD, N. H., 1909.

January	2 690	0.53	0.82	4.07	0.94	23.1
February	4 000	0.78	1.21	3.71	1.26	34.0
March	3 620	0.71	1.10	1.70	1.27	74.7
April	25 400	4.98	7.70	3.51	8.60	245.0
May	14 400	2.82	4.36	4.18	5.03	120.0
June	3 890	0.76	1.18	2.97	1.32	44.4
July	1 490	0.29	0.45	2.82	0.52	18.4
August	836	0.16	0.25	2.68	0.29	10.8
September	1 460	0.28	0.44	5.12	0.49	9.6
October	2 360	0.47	0.72	1.25	0.82	65.5
November	2 380	0.47	0.72	2.07	0.80	38.6
December	2 070	0.41	0.63	1.12	0.72	64.3
The Year	5 370	1.05	1.63	35.20	22.06	62.6

CONNECTICUT RIVER AT ORFORD, N. H., 1910.

January	3 130	0.61	0.95	2.85	1.09	38.2
February	2 000	0.39	0.61	3.49	0.63	18.0
March	12 800	2.51	3.88	1.26	4.47	355.0
April	14 500	2.84	4.39	3.18	4.90	154.0
May	9 080	1.78	2.75	4.60	3.17	68.9
June	6 050	1.18	1.83	3.52	2.04	57.9
July	1 630	0.32	0.49	3.45	0.57	16.5
August	2 430	0.48	0.74	4.23	0.85	20.1
September	1 740	0.34	0.53	4.24	0.59	13.9
October	2 040	0.40	0.62	1.68	0.71	42.2
November	2 510	0.49	0.76	1.98	0.85	42.9
December	1 520	0.30	0.46	2.13	0.53	24.9
The Year	4 960	0.97	1.50	36.61	20.40	55.7

CONNECTICUT RIVER AT ORFORD, N. H., 1911.

January	2 520	0.49	0.76	1.74	0.88	50.6
February	1 360	0.26	0.41	1.92	0.43	22.4
March	2 450	0.48	0.74	3.05	0.86	28.2
April	16 800	3.29	5.09	1.00	5.68	568.0
May	11 300	2.21	3.42	0.92	3.94	428.0
June	2 440	0.48	0.74	3.11	0.82	26.4
July	1 180	0.23	0.36	4.58	0.41	9.0
August	1 620	0.32	0.49	5.57	0.57	10.2
September	2 360	0.47	0.72	3.84	0.80	20.8
October	4 310	0.85	1.31	3.50	1.51	43.1
November	4 340	0.85	1.32	2.28	1.47	64.5
December	8 250	1.62	2.50	2.91	2.88	99.0
The Year	4 930	1.00	1.49	34.42	20.25	58.8

CONNECTICUT RIVER AT SUNDERLAND, MASS.

Discharge measurements made by United States Geological Survey, 1908–1911.

Drainage area, including water surfaces	7 700 sq. miles
Estimated area of water surfaces	60 sq. miles
Area of land surface	7 640 sq. miles

Area of swamps, unknown.

No correction has been made for evaporation or storage.

The drainage area located in Massachusetts, New Hampshire, and Vermont has generally steep slopes, which are for the most part forested, although there are considerable areas under cultivation. A considerable portion of the White Mountain district in New Hampshire is included, as well as the easterly slopes of the Green Mountains in Vermont.

The Deerfield River, a large tributary in southern Vermont and western Massachusetts, is an especially quick spilling stream, with steep slopes and narrow valleys. In southern New Hampshire and a part of Massachusetts the country is flatter, with a considerable number of ponds and reservoirs.

The prevailing surface material is glacial drift.

The elevation above the sea varies from 100 ft. at Sunderland to 6 279 ft. at the top of Mt. Washington. The upper portion of the Deerfield River drainage area reaches an elevation of 3 800 ft.

The discharge is based upon measurements of the elevation of the surface of the water in the river taken twice daily and the use of a rating curve based on occasional current meter measurements. The discharge during the frozen season is affected by ice, which changes the relation of the gage height to the discharge. The figures of monthly discharge during low water periods are probably subject to errors of from 5 to 10 per cent. During the frozen season they may occasionally be in error 15 to 25 per cent.

Although the gagings are not wholly trustworthy, they are given for the reasons already stated in connection with gagings of the river at Orford, N. H.

CONNECTICUT RIVER AT SUNDERLAND, MASS., 1908.
Total drainage area, 7 700 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.
January	13 500	1.55	1.75	2.14	2.02	94.3
February	15 200	1.27	1.97	3.63	2.12	58.4
March	24 700	2.07	3.21	2.02	3.70	183.0
April	32 600	2.73	4.23	2.70	4.72	175.0
May	32 200	2.70	4.18	4.46	4.83	109.0
June	10 300	0.87	1.34	2.11	1.50	71.0
July	3 770	0.32	0.49	3.81	0.56	14.7
August	4 690	0.39	0.61	4.45	0.70	15.7
September	2 010	0.17	0.26	0.91	0.29	31.9
October	2 000	0.17	0.26	1.77	0.30	17.0
November	2 210	0.18	0.29	1.11	0.32	28.8
December	3 710	0.31	0.48	2.49	0.56	22.5
The Year	12 200	1.03	1.59	31.60	21.62	68.4

CONNECTICUT RIVER AT SUNDERLAND, MASS., 1909.

January	5 980	0.50	0.78	3.22	0.90	27.9
February	12 000	1.01	1.56	4.30	1.63	37.9
March	14 700	1.23	1.91	2.29	2.20	96.0
April	56 400	4.73	7.32	3.36	8.17	243.0
May	28 400	2.39	3.69	3.45	4.26	123.0
June	10 600	0.89	1.38	3.25	1.54	47.4
July	3 250	0.27	0.42	3.20	0.49	15.3
August	2 900	0.25	0.38	3.31	0.44	13.3
September	2 550	0.21	0.33	4.66	0.37	7.9
October	4 420	0.37	0.57	1.54	0.66	42.8
November	3 970	0.34	0.52	2.09	0.58	27.7
December	4 520	0.38	0.59	1.99	0.68	34.1
The Year	12 400	1.05	1.62	36.66	21.92	59.7

CONNECTICUT RIVER AT SUNDERLAND, MASS., 1910.

January	13 000	1.09	1.69	3.75	1.95	52.0
February	8 340	0.70	1.08	3.85	1.12	29.1
March	41 600	3.49	5.40	1.14	6.23	545.0
April	30 000	2.52	3.90	2.84	4.35	153.0
May	17 500	1.47	2.27	3.55	2.62	73.8
June	14 600	1.23	1.90	3.18	2.12	66.8
July	3 260	0.27	0.42	2.41	0.49	20.3
August	4 200	0.35	0.54	3.29	0.63	19.1
September	3 100	0.26	0.40	4.00	0.45	11.2
October	3 350	0.28	0.44	1.36	0.50	36.8
November	4 950	0.41	0.64	2.73	0.72	26.4
December	2 810	0.23	0.36	2.00	0.42	21.0
The Year	12 200	1.03	1.59	34.10	21.60	63.4

CONNECTICUT RIVER AT SUNDERLAND, MASS., 1911.

January	10 000	0.84	1.30	2.09	1.50	71.7
February	4 200	0.36	0.55	2.33	0.57	24.5
March	8 960	0.75	1.16	3.42	1.34	39.2
April	36 400	3.06	4.73	1.24	5.28	426.0
May	19 600	1.65	2.55	1.33	2.94	221.0
June	6 060	0.51	0.79	3.05	0.88	28.8
July	2 260	0.19	0.29	4.19	0.34	8.1
August	2 860	0.24	0.37	4.43	0.43	9.7
September	5 470	0.46	0.71	3.95	0.79	20.0
October	16 300	1.37	2.12	5.31	2.44	46.0
November	12 600	1.06	1.64	2.59	1.83	70.6
December	18 000	1.51	2.34	2.87	2.70	94.0
The Year	11 900	1.00	1.55	36.80	21.04	57.7

The precipitation upon this drainage area is deduced from United States Weather Bureau records at the following stations: Bloomfield, Vt.; St. Johnsbury, Vt.; Chelsea, Vt.; Bethlehem, N. H.; Grafton, N. H.; Alstead, N. H.; Cavendish, Vt.; Woodstock, Vt.; Jacksonville, Vt.; Keene, N. H.; Fitchburg, Mass.; Turners Falls, Mass.

The mean precipitation deduced from these records is probably considerably too low, as none of the stations are located in the regions of high elevation, where the precipitation is the greatest. This probably accounts in part for the high percentage of rainfall running off, as given in the tables.

DEERFIELD RIVER AT SHELBURNE FALLS, MASS.

Discharge measurements made by United States Geological Survey, 1908–1911.

Drainage area, including water surfaces	501 sq. miles
Estimated area of water surfaces	1 sq. mile
Area of land surface	500 sq. miles

Area of swamps, very small.

No correction is made for evaporation or storage.

The drainage area consists of steep slopes and narrow valleys, nearly all forested and with practically no storage. Its elevation ranges from 260 to 3 800 ft. above sea level and averages about 1 800 ft.

The surface material is glacial drift, most of it unmodified, with the steeper slopes of ledge and bowlders.

The discharge is measured at the plant of the Greenfield Electric Light and Power Company below Shelburne Falls. The results are based upon three daily readings of the heights of water at the dam and hourly readings of wheel gate openings and head. Low water estimates of monthly discharge are fairly good, as at such times practically all water is used by the wheels. At medium and high water, estimates are fairly good except at occasional intervals when the flashboards on the dam are temporarily displaced.

The United States Weather Bureau records of precipitation

at Jacksonville, Vt. (elevation about 1 400 ft.) are used for the period January, 1908, to November, 1911, inclusive, except where records are omitted, in which case Manchester, Vt., is used. Beginning with December, 1911, the Weather Bureau records at Somerset, Vt. (elevation 2 096 ft.), are used. The precipitation at Jacksonville is undoubtedly less than the average precipitation in the Deerfield basin above Shelburne Falls, owing to the higher average elevation of the basin.

DEERFIELD RIVER AT SHELBURNE FALLS, MASS., 1908.
Total drainage area, 501 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.
January	731	0.94	1.46	3.86	1.68	43.5
February	965	1.25	1.93	4.09	2.08	50.9
March	2 210	2.86	4.42	1.20	5.08	423.0
April	2 550	3.28	5.09	2.57	5.68	221.0
May	2 700	3.48	5.39	3.43	6.21	181.0
June	620	0.80	1.24	1.84	1.38	75.0
July	370	0.48	0.74	4.61	0.85	18.4
August	274	0.36	0.55	3.33	0.63	18.9
September	85	0.11	0.17	0.83	0.19	22.9
October	115	0.15	0.23	2.20	0.27	12.2
November	207	0.26	0.41	0.96	0.46	48.0
December	236	0.30	0.47	2.46	0.54	21.9
The Year	922	1.19	1.84	31.38	25.05	79.9

DEERFIELD RIVER AT SHELBURNE FALLS, MASS., 1909.

January	730	0.94	1.46	4.40	1.68	38.2
February	1 230	1.59	2.46	4.47	2.56	57.2
March	904	1.16	1.80	1.67	2.08	125.0
April	5 060	6.52	10.1	2.63	11.27	428.0
May	1 350	1.74	2.70	4.47	3.10	69.3
June	689	0.89	1.38	2.85	1.54	54.0
July	152	0.19	0.30	1.68	0.35	20.8
August	249	0.32	0.50	3.90	0.57	14.6
September	313	0.40	0.62	5.45	0.70	12.8
October	314	0.41	0.63	4.95	0.72	14.5
November	284	0.37	0.57	2.39	0.63	26.3
December	242	0.31	0.48	0.88	0.56	63.5
The Year	960	1.24	1.92	39.74	25.76	64.8

DEERFIELD RIVER AT SHELBURNE FALLS, MASS., 1910.

January	1 500	1.93	2.99	3.07	3.45	112.0
February	970	1.25	1.94	2.99	2.02	67.0
March	3 630	4.68	7.25	1.43	8.35	583.9
April	1 850	2.38	3.69	2.16	4.12	190.0
May	851	1.10	1.70	4.51	1.96	43.5
June	1 124	1.45	2.24	2.81	2.50	89.0
July	163	0.21	0.33	2.65	0.38	14.3
August	110	0.14	0.22	2.00	0.25	12.5
September	163	0.21	0.33	4.92	0.37	7.5
October	132	0.17	0.26	0.89	0.30	33.7
November	307	0.39	0.61	3.44	0.68	19.8
December	169	0.22	0.34	0.38	0.61	160.0
The Year	914	1.19	1.84	31.25	24.99	79.6

DEERFIELD RIVER AT SHELBURNE FALLS, MASS., 1911.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.
January	997	1.28	1.99	4.04	2.29	56.8
February	301	0.39	0.60	5.06	0.62	12.2
March	947	1.22	1.89	4.57	2.18	47.6
April	3 230	4.17	6.46	2.24	7.21	322.0
May	986	1.27	1.97	2.06	2.27	110.0
June	774	1.00	1.55	4.94	1.73	35.0
July	148	0.19	0.30	1.21	0.34	28.1
August	234	0.30	0.47	2.00	0.54	27.0
September	668	0.86	1.33	5.20	1.49	28.7
October	2 130	2.75	4.26	10.98	4.91	44.8
November	1 180	1.52	2.36	1.81	2.63	145.0
December	1 100	1.42	2.19	4.04	2.52	62.4
The Year	1 060	1.36	2.11	48.15	28.73	59.7

MERRIMACK RIVER AT LAWRENCE, MASS.

Information furnished by R. A. Hale, Principal Assistant Engineer of the Essex Company, Lawrence, Mass.

Yield measured by engineers of Essex Company, 1908–1912.

Drainage area, including water surfaces . . . 4 452 sq. miles

The area of water surfaces has not been carefully estimated, but there are included in the drainage area Lake Winnipiseogee (72 sq. miles), Squam Lake (14 sq. miles), and a great many smaller lakes, which, according to a rough estimate, aggregate about 97 sq. miles, making the total area of water surface included in lakes and ponds 183 sq. miles. The mill ponds and water surfaces of the river from the dam at Lawrence to Franklin, N. H., including some of the larger tributaries, would make an additional water surface of about 17 sq. miles, making a total area of water surface of about 200 sq. miles. According to this estimate the water surfaces represent 4.5 per cent. of the whole drainage area.

The area of swamps is unknown, but as part of the area is rather flat, the area of swamps is considerable. Owing to the large area of lakes, ponds, and reservoirs, the summer flow is materially augmented by the water drawn from them, but it has not been practicable to make corrections for storage or evaporation, and the discharge given is the flow of the stream at Lawrence.

The drainage area as above given does not include 212 sq. miles of the original drainage area, which has been appropriated for the water supply of the Metropolitan Water District, and the gagings at Lawrence are corrected for the water which flows past the Metropolitan Water Works dams.

The greater part of the drainage area lies at rather a low elevation. The river at Lawrence is about 40 ft. above sea level. Lake Winnipiseogee, which is far toward the upper end of the drainage area, is 500 ft. above sea level. At the extreme head waters, however, in the Pemigewasset valley, the Franconia Mountains rise to a maximum elevation of 5 260 ft. The mean elevation of the drainage area probably is between 500 and 700 ft.

The precipitation is an average of that recorded at 34 rainfall stations located in different parts of the drainage area or a short distance outside of it. In making the average, however, five stations on the Wachusett drainage area and five upon the Sudbury and Cochituate drainage areas are averaged and each treated as one station in making the general average.

The rain gages are generally located in the valleys, and their average elevation is much less than the average elevation of the drainage area. It is, therefore, probable that the actual precipitation upon the drainage area is larger than that recorded in the tables.

MERRIMACK RIVER AT LAWRENCE, MASS., 1908.

Total drainage area, 4 452 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area.	Precipitation Collected.	
	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	8 665	1.258	1.946	2.69	2.244	83.4
February	7 335	1.063	1.648	4.17	1.777	42.6
March	11 125	1.612	2.499	2.44	2.881	118.1
April	11 808	1.712	2.652	2.05	2.959	144.3
May	11 440	1.660	2.570	4.65	2.964	63.7
June	4 148	0.602	0.932	1.02	1.040	102.0
July	2 322	0.337	0.522	3.86	0.602	15.6
August	2 972	0.431	0.668	4.93	0.770	15.6
September	1 686	0.245	0.379	0.88	0.423	48.1
October	1 467	0.213	0.330	2.21	0.381	17.2
November	1 575	0.228	0.354	1.06	0.395	37.3
December	1 870	0.271	0.420	2.86	0.484	16.9
The Year	5 534	0.804	1.243	32.82	16.920	51.6

MERRIMACK RIVER AT LAWRENCE, MASS., 1909.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area.	Precipitation Collected.	
	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	3 014	0.437	0.677	3.87	0.781	20.2
February	6 957	1.010	1.563	4.84	1.626	33.6
March	7 545	1.095	1.695	3.27	1.955	59.8
April	15 156	2.199	3.404	4.05	3.799	93.8
May	8 687	1.260	1.951	2.44	2.250	92.2
June	4 221	0.612	0.948	2.73	1.058	38.8
July	1 992	0.289	0.447	2.42	0.515	21.3
August	1 675	0.243	0.376	2.79	0.434	15.6
September	1 645	0.238	0.369	4.36	0.412	9.4
October	1 878	0.273	0.422	1.24	0.487	39.3
November	1 726	0.250	0.388	2.45	0.433	17.7
December	2 242	0.325	0.504	3.17	0.581	18.3
The Year	4 728	0.686	1.062	37.63	14.331	38.1

MERRIMACK RIVER AT LAWRENCE, MASS., 1910.

January	4 642	0.675	1.043	4.20	1.203	28.6
February	4 332	0.628	0.973	4.28	1.012	23.6
March	16 075	2.330	3.611	1.22	4.164	341.3
April	10 885	1.580	2.445	2.95	2.729	92.5
May	6 719	0.974	1.509	2.12	1.740	82.1
June	4 795	0.695	1.077	3.70	1.202	32.5
July	1 773	0.257	0.398	2.00	0.459	23.0
August	2 037	0.296	0.458	3.07	0.528	17.2
September	1 766	0.256	0.397	3.12	0.443	14.2
October	1 335	0.194	0.300	1.43	0.346	24.2
November	2 035	0.295	0.457	3.04	0.510	16.8
December	1 490	0.216	0.335	2.30	0.386	16.8
The Year	4 824	0.700	1.084	33.43	14.722	44.0

MERRIMACK RIVER AT LAWRENCE, MASS., 1911.

January	2 778	0.403	0.624	2.28	0.720	31.6
February	2 147	0.311	0.482	2.55	0.501	19.6
March	5 554	0.805	1.248	3.46	1.439	41.6
April	13 557	1.968	3.045	1.66	3.398	204.7
May	6 055	0.878	1.360	1.22	1.568	128.5
June	2 455	0.356	0.551	2.63	0.615	23.4
July	1 184	0.172	0.266	3.99	0.307	7.7
August	1 461	0.212	0.328	4.50	0.378	8.4
September	1 937	0.281	0.435	3.34	0.485	14.5
October	4 089	0.593	0.918	4.03	1.059	26.3
November	4 668	0.677	1.049	3.49	1.171	33.6
December	5 718	0.830	1.284	3.04	1.481	48.7
The Year	4 300	0.624	0.966	36.19	13.122	36.3

MERRIMACK RIVER AT LAWRENCE, MASS., 1912.

January	3 572	0.518	0.802	....	....	....
February	3 145	0.456	0.706	....	....	....
March	12 346	1.791	2.773	....	....	....

CAMBRIDGE, MASS., WATER WORKS.

Stony Brook.

Information furnished by L. M. Hastings, city engineer.

The yield of Stony Brook is measured at the Stony Brook dam in Waltham, 1908–February, 1912, inclusive.

Drainage area, including water surfaces	23.57 sq. miles
Area of water surfaces	1.00 sq. mile
Area of land surface	22.57 sq. miles

There are several swamps in the drainage area, the aggregate area of which is not definitely known but is approximately 2 sq. miles. No account was taken of these swamps in computing the accompanying tables.

Full corrections have been made for water drawn from or added to storage. The amount of storage in the ground surrounding the reservoirs is rather small, and no allowance has been made for such storage in the records of run-off. There is some percolation past the dam where the measurements are made, and some water is run through a small pipe to maintain the level of a

CAMBRIDGE, MASS., WATER WORKS, 1908.

Yield of Stony Brook at Stony Brook Dam. Total drainage area, 23.57 sq. miles. Area of land surface, 22.57 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	996.0	45	1 041.0	1.423	2.206	1.425	2.208	3.53	2.540	71.9	2.542	72.0
Feb.	824.5	68	892.5	1.259	1.949	1.305	2.020	4.83	2.102	43.5	2.179	45.1
Mar.	1 182.8	34	1 216.8	1.694	2.625	1.666	2.579	3.67	3.014	82.1	2.972	81.0
Apr.	712.3	−27	685.3	1.051	1.628	0.969	1.499	1.44	1.816	126.0	1.672	119.4
May	495.7	−5	490.7	0.710	1.098	0.671	1.038	4.19	1.263	30.1	1.197	28.6
June	223.9	−72	151.9	0.332	0.514	0.215	0.323	1.40	0.571	40.8	0.371	26.5
July	75.5	−37	38.5	0.108	0.167	0.053	0.082	3.86	0.193	5.0	0.094	2.4
Aug.	45.5	−22	23.5	0.065	0.101	0.032	0.050	4.26	0.116	2.7	0.057	1.3
Sept.	43.7	−56	−12.3	0.065	0.101	−0.017	−0.026	0.88	0.111	12.6	−0.030	−3.4
Oct.	15.0	−8	7.0	0.021	0.033	0.010	0.016	2.68	0.038	1.4	0.017	0.6
Nov.	33.0	−23	10.0	0.049	0.076	0.014	0.022	0.92	0.084	9.1	0.024	2.6
Dec.	70.0	17	87.0	0.100	0.155	0.119	0.184	2.50	0.178	7.1	0.212	8.5
Year	4 717.9	−86	4 631.9	0.572	0.886	0.537	0.831	34.16	12.026	35.2	11.307	33.1

CAMBRIDGE, MASS., WATER WORKS, 1909.

Jan.	155.0	57	212.0	0.222	0.344	0.290	0.449	4.21	0.395	11.6	0.517	12.3
Feb.	1 196.6	71	1 267.6	1.893	2.930	1.921	2.973	5.14	3.050	59.3	3.095	60.2
Mar.	923.5	39	962.5	1.320	2.041	1.317	2.038	3.95	2.353	59.6	2.350	58.5
Apr.	966.0	17	983.0	1.424	2.203	1.390	2.152	3.95	2.463	62.3	2.399	60.7
May	694.7	−42	652.7	0.993	1.534	0.893	1.382	2.04	1.771	86.8	1.593	78.1
June	336.5	−42	294.5	0.497	0.768	0.417	0.646	3.11	0.858	27.6	0.719	23.1
July	71.6	−60	11.6	0.102	0.158	0.016	0.025	2.50	0.182	7.3	0.028	1.1
Aug.	48.9	−45	3.9	0.070	0.108	0.005	0.008	2.90	0.125	4.3	0.010	0.3
Sept.	67.5	9	76.5	0.100	0.155	0.108	0.167	4.66	0.172	3.7	0.187	4.0
Oct.	48.2	−34	14.2	0.069	0.107	0.019	0.029	1.18	0.123	10.4	0.035	3.0
Nov.	142.0	16	158.0	0.210	0.325	0.223	0.345	3.20	0.362	11.3	0.386	12.1
Dec.	168.6	48	216.6	0.242	0.374	0.296	0.458	4.26	0.430	10.1	0.529	12.4
Year	4 819.1	34	4 853.1	0.586	0.906	0.564	0.872	41.10	12.284	29.9	11.848	28.8

CAMBRIDGE, MASS., WATER WORKS, 1910.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	964.4	70	1 034.4	1.377	2.131	1.414	2.188	4.98	2.459	49.4	2.524	50.7
Feb.	1 077.6	49	1 126.6	1.705	2.640	1.708	2.642	3.88	2.747	70.8	2.751	70.9
Mar.	1 378.2	−3	1 375.2	1.970	3.050	1.882	2.913	1.53	3.513	230.0	3.359	219.3
Apr.	434.9	−10	424.9	0.642	0.994	0.601	0.930	2.39	1.108	46.4	1.037	43.4
May	262.4	−60	202.4	0.376	0.582	0.277	0.429	1.03	0.669	64.9	0.494	48.0
June	303.5	−30	273.5	0.448	0.694	0.387	0.599	3.82	0.773	20.2	0.668	17.5
July	59.9	−72	−12.1	0.086	0.133	−0.017	−0.026	1.85	0.153	8.3	−0.030	−16.2
Aug.	90.6	−67	23.6	0.130	0.201	0.032	0.050	1.64	0.231	14.1	0.058	3.5
Sept.	43.6	−24	19.6	0.064	0.099	0.028	0.043	2.76	0.111	4.0	0.048	1.7
Oct.	76.4	−30	46.4	0.109	0.169	0.064	0.099	1.44	0.195	13.5	0.113	7.9
Nov.	101.9	31	132.9	0.151	0.234	0.188	0.291	4.03	0.260	6.4	0.324	8.0
Dec.	289.4	12	301.4	0.414	0.640	0.412	0.638	2.22	0.737	33.2	0.736	33.2
Year	5 082.8	−134	4 948.8	0.618	0.957	0.575	0.890	31.57	12.956	41.1	12.082	38.3

CAMBRIDGE, MASS., WATER WORKS, 1911.

Jan.	290.0	32	322.0	0.415	0.643	0.441	0.684	2.83	0.739	26.2	0.786	27.8
Feb.	371.9	33	404.9	0.588	0.910	0.613	0.949	2.93	0.948	32.4	0.939	33.8
Mar.	699.4	28	727.4	1.000	1.549	0.995	1.540	3.32	1.782	53.7	1.775	53.5
Apr.	589.3	−14	575.3	0.870	1.345	0.814	1.260	2.17	1.502	69.2	1.405	64.8
May	195.9	−66	129.9	0.280	0.434	0.178	0.275	0.65	0.500	76.9	0.317	48.8
June	190.8	−32	158.8	0.282	0.436	0.225	0.348	3.68	0.487	13.2	0.388	10.5
July	86.5	−27	59.5	0.124	0.192	0.081	0.125	4.40	0.220	5.0	0.145	3.3
Aug.	86.6	−6	80.6	0.124	0.192	0.110	0.170	5.14	0.221	4.3	0.196	3.8
Sept.	149.1	−9	140.1	0.220	0.341	0.198	0.307	3.61	0.380	10.5	0.342	9.5
Oct.	308.4	−3	305.4	0.441	0.684	0.418	0.648	2.96	0.786	26.6	0.746	25.2
Nov.	508.5	40	548.5	0.750	1.160	0.776	1.202	4.54	1.297	28.6	1.340	29.5
Dec.	515.9	37	552.9	0.739	1.141	0.757	1.172	3.64	1.315	36.1	1.350	37.1
Year	3 992.3	12	4 005.3	0.485	0.752	0.465	0.720	39.87	10.177	25.5	9.779	24.5

CAMBRIDGE, MASS., WATER WORKS, 1912.

Jan.	486.0	29	515.0	0.695	1.075	0.705	1.091	2.65	1.238	46.7	1.257	47.5
Feb.	765.3	24	789.3	1.170	1.812	1.154	1.790	2.43	2.010	82.7	1.927	79.3

pond below the dam. No allowance has been made in the records of run-off for these quantities, which may amount to from 2 to 4 per cent. of the total run-off of dry years. Most of the drainage area is gently undulating, and in some parts there are hills from 100 to 200 ft. high.

The elevation above sea level ranges from 70 to 380 ft. and averages about 180 ft.

The quantity of water drawn for use by the city is measured as it flows through the pipe leading from Stony Brook dam to Fresh Pond, and the quantity is roughly checked by the amount pumped from the pond for the supply of the city. The quantity of water wasted is determined from records of the depth on the

spillway of the Stony Brook dam. During the years under consideration, comparatively little water was wasted.

Standard rain gages are maintained at the Stony Brook and Hobbs Brook reservoirs by the keepers of the reservoirs, under the supervision of the superintendent of the water works and the city engineer.

HOLYOKE, MASS., WATER WORKS.

Manhan River.

Information furnished by James L. Tighe, consulting engineer.

The yield of the southwest branch of the Manhan River was measured at the confluence of Manhan and Tucker brooks in Southampton, Mass.

The records furnished cover the years 1899 and 1900, which were very dry, as well as the years 1908–1911, inclusive.

Drainage area, which includes practically no water surfaces, 13 sq. miles.

Area of undrained swamps, about 250 acres.

The drainage area is mountainous in character, with precipitous slopes. The soil is rocky and gravelly, with considerable humus in the wooded parts; about 65 per cent. is forested.

The elevation above the sea ranges from 440 ft. at the southerly end to 1 550 ft. at the watershed line, six miles north, and averages about 950 ft.

HOLYOKE, MASS., WATER WORKS, 1899.

Yield of southwest branch of the Manhan River. Total drainage area (all land surface), 13 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu Ft. per Sec.		Inches.	Per Cent.
January	492.3	1.470	2.274	3.04	2.62	86.09
February	263.1	0.723	1.118	3.36	1.16	34.66
March	658.2	1.633	2.526	6.87	2.91	42.41
April	1 921.3	4.926	7.622	1.92	8.50	442.95
May	332.9	0.826	1.278	1.31	1.47	112.48
June	97.5	0.248	0.383	2.43	0.43	17.58
July	146.9	0.364	0.563	5.07	0.65	12.81
August	51.6	0.128	0.198	1.94	0.23	11.76
September	116.2	0.298	0.461	5.01	0.51	10.26
October	79.6	0.198	0.303	1.31	0.35	26.89
November	169.2	0.434	0.671	3.16	0.75	23.70
December	181.9	0.451	0.697	2.86	0.80	28.14
The Year	4 510.7	0.975	1.508	38.28	20.38	53.29

HOLYOKE, MASS., WATER WORKS, 1900.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	190.2	0.472	0.733	3.59	0.84	23.45
February	1 510.4	4.150	6.421	10.28	6.69	65.04
March	1 128.7	2.801	4.344	5.54	4.99	90.16
April	774.0	1.985	3.071	1.88	3.42	181.75
May	613.0	1.521	2.353	4.44	2.71	61.11
June	145.8	0.374	0.578	1.78	0.64	36.26
July	60.0	0.149	0.235	2.49	0.16	10.67
August	68.3	0.170	0.263	3.91	0.30	7.72
September	30.7	0.079	0.122	2.11	0.13	6.42
October	73.6	0.183	0.283	3.42	0.32	9.52
November	387.3	0.993	1.536	4.31	1.71	39.77
December	383.2	0.951	1.471	3.27	1.70	51.87
The Year	5 365.2	1.152	1.784	47.02	23.61	50.21

HOLYOKE, MASS., WATER WORKS, 1908.

January	716.7	1.778	2.751	3.41	3.17	93.03
February	515.6	1.463	2.263	4.84	2.44	50.45
March	966.4	2.472	3.825	3.44	4.41	128.22
April	758.5	1.945	3.009	3.19	3.36	105.25
May	1 146.1	2.844	4.400	7.19	5.07	70.56
June	287.4	0.737	1.140	1.70	1.27	74.83
July	169.3	0.420	0.649	4.40	0.75	17.04
August	138.4	0.343	0.530	4.10	0.61	14.94
September	66.4	0.170	0.269	1.85	0.29	15.88
October	96.0	0.238	0.368	2.62	0.42	16.22
November	98.7	0.253	0.391	1 02	0.43	42.84
December	110.8	0.275	0.425	2.91	0.49	16.85
The Year	5 070.3	1.078	1.668	40.67	22.71	55.80

HOLYOKE, MASS., WATER WORKS, 1909.

January	275.1	0.683	1.056	4.33	1.02	28.12
February	754.3	2.072	3.206	6.41	3.34	52.08
March	963.6	2.391	3.699	5.29	4.26	80.54
April	1 486.5	3.812	5.898	6.45	6.58	102.01
May	628.4	1.559	2.412	4.00	2.78	69.54
June	287.2	0.736	1.107	3.12	1.27	40.73
July	50.6	0.126	0.194	1.16	0.22	19.31
August	115.7	0.287	0.444	4.70	0.51	10.90
September	119.0	0.305	0.471	4.36	0.53	12.08
October	72.2	0.179	0.276	1.32	0.32	24.23
November	75.4	0.193	0.298	2.34	0.33	14.25
December	171.8	0.426	0.659	3.64	0.76	20.90
The Year	4 999.8	1.064	1.643	47.12	21.92	46.52

HOLYOKE, MASS., WATER WORKS, 1910.

January	983.3	2.425	3.751	7.97	4.33	54.29
February	323.1	0.888	1.374	6.88	1.43	20.79
March	1 485.8	3.687	5.705	1.60	6.57	411.06
April	1 127.6	2.891	4.473	5.36	4.99	93.13
May	563.0	1.397	2.161	3.58	2.49	69.62
June	465.9	1.195	1.849	3.70	2.06	55.75
July	53.9	0.134	0.207	1.67	0.24	14.29
August	101.1	0.251	0.388	4.48	0.45	9.99
September	75.6	0.194	0.300	3.07	0.33	10.90
October	52.9	0.131	0.202	0.72	0.23	32.50
November	176.2	0.452	0.699	5.59	0.78	13.95
December	105.5	0.262	0.405	1.87	0.46	24.99
The Year	5 513.9	1.159	1.793	46.49	24.36	52.39

HOLYOKE, MASS., WATER WORKS, 1911.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.
January	142.7	0.354	0.574	2.08	0.62	29.65
February	76.1	0.209	0.323	1.80	0.33	18.27
March	526.4	1.306	2.020	4.21	2.27	54.04
April	686.8	1.761	2.724	2.61	2.97	113.75
May	228.0	0.566	0.875	1.13	0.98	87.22
June	333.9	0.856	1.324	4.21	1.44	34.28
July	170.0	0.422	0.653	4.17	0.73	17.62
August	162.9	0.404	0.625	6.71	0.70	10.49
September	115.0	0.294	0.455	4.57	0.49	10.88
October	980.5	2.433	3.764	8.86	4.24	47.83
November	527.4	1.352	2.092	2.57	2.28	88.70
December	413.6	1.026	1.587	2.98	1.79	59.99
The Year	4 363.3	0.915	1.461	45.90	18.84	41.04

The discharge measurements were made at two sharp crested weirs, one on each brook, using a hook gage to determine the heights. Readings were usually taken twice a day, and more frequently in rainy weather.

Records of precipitation were obtained from a standard rain gage 8 in. in diameter, located 10 in. above the surface of the ground near the weirs. The snowfall was determined from melting the snow collected in the gage.

Judging from experience elsewhere, the average precipitation on the drainage area would be greater than that recorded, because of the much higher elevation of a large portion of the area.

METROPOLITAN WATER WORKS.

Wachusett Drainage Area.

Information furnished by Dexter Brackett, chief engineer.

The records presented give the yield of this drainage area at the Wachusett Dam for the years 1908 to July, 1914, inclusive.

Drainage area, including water surfaces		118.19 sq. miles
Area of water surfaces of reservoirs, ponds, and streams,	8.59	
A portion of the area of swamps reckoned as water surfaces as follows:		
30 per cent. of 0.68 sq. miles of drained swamps . . .	0.20	
40 per cent. of 2.91 sq. miles of undrained swamps . .	1.16	
Total area reckoned as water surfaces		9.95 sq. miles
Area of land (upland) surface		108.24 sq. miles

The division of swamps into equivalent water surfaces and upland, as above indicated, has already been discussed in the report.

Full corrections are made for the water drawn from or added to storage, except that no allowance is made for the storage in the ground surrounding the reservoir. Such storage, although quite large in total amount, is small in proportion to the storage in the reservoir.

There is no appreciable percolation past the main dam or the south dike of the reservoir, but about one per cent. of the flow in the years 1908 to 1913, inclusive, percolated past the location of the north dike. Allowance was made for this percolation in and after 1910, but not in the previous years. Some water was diverted to the city of Worcester after August 1, 1911, and due allowance has been made therefor in the records.

The drainage area is generally hilly, and increasingly so toward the western portion of the area. The soil of the lower lands is generally sandy and gravelly, while that of many of the hills consists of unmodified drift. From one third to one half of the area is forested. The trees are cut from time to time and are replaced by a new growth. There is considerable ground water stored in the sand and gravel beds, which assists in equalizing the natural flow of the streams.

The elevation above sea level ranges from 390 to 2 108 ft. and averages about 750 ft.

During the period under consideration nearly all the water has been discharged through the Wachusett aqueduct and most of the time measured over a weir which was calibrated by current meter measurements made in the aqueduct. The depth on the weir was measured by an automatic recording float gage. In the latter part of 1911, a change in the method of measurements was made, caused by the introduction of hydro-electric machinery, and Venturi meters calibrated by current meter measurements were used to determine the flow. The quantity of water wasted at the spillway of the dam during the period under consideration amounted to only one per cent. of the yield, so that there has been practically no error due to spillway measurements.

The precipitation is measured at four stations, well distributed

METROPOLITAN WATER WORKS, 1908.

Yield of Wachusett drainage area. Total drainage area, 118.19 sq. miles. Area of land surface, 108.24 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	5 965.8	403	6 368.8	1.780	2.754	1.738	2.689	3.40	3.17	93.2	3.10	91.3
Feb.	5 320.5	628	5 948.5	1.696	2.624	1.736	2.685	4.82	2.83	58.7	2.90	60.1
Mar.	7 847.7	183	8 030.7	2.340	3.622	2.192	3.391	2.77	4.17	150.5	3.91	141.2
Apr.	4 560.8	−61	4 499.8	1.406	2.177	1.269	1.964	2.62	2.42	92.4	2.19	83.5
May	5 030.4	153	5 183.4	1.499	2.319	1.415	2.188	5.34	2.67	50.0	2.52	47.3
June	2 163.3	−734	1 429.3	0.667	1.032	0.403	0.624	1.29	1.15	89.1	0.70	53.9
July	1 168.2	−361	807.2	0.348	0.538	0.220	0.341	3.85	0.62	16.1	0.39	10.2
Aug.	1 455.8	167	1 622.8	0.434	0.672	0.443	0.685	6.49	0.77	11.9	0.79	12.2
Sept.	819.6	−509	310.6	0.253	0.391	0.088	0.136	1.04	0.44	42.3	0.15	14.5
Oct.	742.9	−163	579.9	0.221	0.342	0.158	0.245	2.13	0.39	18.3	0.28	13.3
Nov.	633.3	−189	444.3	0.195	0.302	0.125	0.194	1.05	0.34	32.4	0.22	20.6
Dec.	1 183.2	236	1 419.2	0.353	0.548	0.387	0.599	3.03	0.63	20.8	0.69	22.8
Year	36 891.5	−247	36 644.5	0.931	1.440	0.847	1.311	37.83	19.60	51.8	17.84	47.2

METROPOLITAN WATER WORKS, 1909.

Jan.	1 791.6	377	2 168.6	0.534	0.827	0.592	0.916	3.52	0.95	27.0	1.056	30.0
Feb.	7 711.5	748	8 459.5	2.542	3.935	2.556	3.655	6.10	4.10	67.2	4.118	67.5
Mar.	7 387.3	414	7 801.3	2.202	3.410	2.129	3.294	4.38	3.93	89.7	3.798	86.8
Apr.	8 129.0	459	8 588.0	2.500	3.870	2.422	3.748	5.71	4.32	75.6	4.181	73.3
May	4 752.2	−311	4 441.2	1.416	2.192	1.212	1.876	2.65	2.53	95.4	2.162	81.7
June	2 672.3	−433	2 239.3	0.824	1.276	0.632	0.977	3.03	1.42	46.9	1.091	36.0
July	1 149.0	−295	854.0	0.345	0.534	0.233	0.361	4.25	0.61	14.4	0.416	9.8
Aug.	1 030.7	−322	708.7	0.307	0.475	0.193	0.299	3.59	0.55	15.3	0.345	9.6
Sept.	772.9	−37	735.9	0.238	0.368	0.208	0.321	3.90	0.41	10.5	0.358	9.2
Oct.	572.0	−243	329.0	0.171	0.265	0.090	0.139	1.70	0.30	17.6	0.160	9.4
Nov.	1 376.7	−90	1 286.7	0.424	0.656	0.363	0.561	1.68	0.73	43.5	0.627	37.2
Dec.	1 581.9	386	1 967.9	0.472	0.731	0.537	0.831	3.99	0.84	21.0	0.958	24.0
Year	38 927.1	653	39 580.1	0.985	1.525	0.918	1.420	44.30	20.69	46.5	19.270	43.3

METROPOLITAN WATER WORKS, 1910.

Jan.	6 005.1	759	6 764.1	1.790	2.770	1.846	2.857	5.86	3.20	54.6	3.293	56.2
Feb.	5 433.4	671	6 104.4	1.792	2.772	1.845	2.854	5.24	2.89	55.1	2.972	56.7
Mar.	9 774.7	−104	9 670.7	2.912	4.506	2.640	4.084	1.09	5.19	476.0	4.709	432.8
Apr.	3 659.2	7	3 666.2	1.127	1.745	1.034	1.600	3.01	1.94	64.5	1.785	59.2
May	2 631.2	−402	2 229.2	0.784	1.213	0.608	0.941	2.13	1.40	65.7	1.085	50.9
June	3 123.3	−203	2 920.3	0.962	1.489	0.824	1.274	4.36	1.66	38.1	1.422	32.6
July	985.6	−759	226.6	0.294	0.455	0.062	0.096	1.52	0.52	34.2	0.110	7.2
Aug.	953.9	−273	680.9	0.287	0.444	0.186	0.288	3.87	0.51	13.2	0.331	8.6
Sept.	722.2	−209	513.2	0.223	0.345	0.145	0.224	2.86	0.38	13.3	0.250	8.7
Oct.	530.7	−280	250.7	0.158	0.245	0.068	0.106	1.40	0.28	20.0	0.122	8 7
Nov.	957.5	299	1 256.5	0 295	0.456	0.354	0.548	4.17	0.51	12 2	0.612	14.7
Dec.	1 307.5	125	1 432.5	0.390	0.604	0.391	0.605	2.34	0.70	29.9	0.697	29.8
Year	36 084.3	−369	35 715.3	0.913	1.413	0.828	1.281	37.85	19.18	50.7	17.388	45.9

METROPOLITAN WATER WORKS, 1911.

Jan.	2 542.6	290	2 832.6	0.758	1.173	0.773	1.196	2.91	1.35	46.4	1.379	47.5
Feb.	1 864.6	203	2 067.6	0.615	0.952	0.625	0.967	2.43	0.99	40.7	1.007	41.4
Mar.	4 599.6	308	4 907.6	1.371	2.122	1.339	2.072	3.79	2.44	64.4	2.389	63.0
Apr.	5 055.2	−118	4 938.2	1.556	2.409	1.393	2.155	2.22	2.68	120.7	2.404	108.5
May	2 158.7	−471	1 687.7	0.643	0.995	0.461	0.713	1.59	1.15	72.4	0.822	51.6
June	1 767.3	−523	1 244.3	0.542	0.839	0.351	0.543	2.37	0.94	39.6	0.606	25.5
July	765.0	−558	207.0	0.228	0.353	0.057	0.087	2.53	0.41	16.2	0.101	4.0
Aug.	696.1	−7	689.1	0.208	0.322	0.188	0.291	5.46	0.37	6.8	0.335	6.1
Sept.	812.2	−169	643.2	0.250	0.387	0.181	0.281	3.04	0.43	14.1	0.313	10.3
Oct.	2 311.5	318	2 629.5	0.689	1.066	0.718	1.111	5.24	1.23	23.5	1.280	24.4
Nov.	3 380.3	288	3 668.3	1.041	1.612	1.035	1.601	4.14	1.80	43.5	1.786	43.1
Dec.	3 679.0	229	3 908.0	1.096	1.697	1.067	1.650	3.01	1.96	65.1	1.903	63.2
Year	29 633.1	−219	29 423.1	0.750	1.161	0.632	1.955	38.73	15.75	40.7	14.325	37.0

METROPOLITAN WATER WORKS, 1912.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	2 609.8	250	2 859.8	0.778	1.204	0.781	1.208	2.57	1.39	54.1	1.392	54.2
Feb.	2 963.2	214	3 177.2	0.946	1.464	0.927	1.434	2.42	1.58	65.3	1.547	63.8
Mar.	9 739.0	633	10 372.0	2.903	4.490	2.831	4.380	5.69	5.18	91.0	5.050	88.8
Apr.	7 901.4	186	8 087.4	2.433	3.770	2.280	8.530	4.06	4.20	103.5	3.938	97.0
May	6 359.4	224	6 583.4	1.895	2.930	1.797	2.780	5.76	3.38	58.7	3.206	55.7
June	2 048.7	−875	1 173.7	0.630	0.975	0.331	0.512	0.48	1.09	227.0	0.571	119.6
July	1 063.0	−570	493.0	0.318	0.493	0.135	0.208	2.65	0.56	21.1	0.240	9.1
Aug.	899.2	−440	459.2	0.268	0.415	0.125	0.194	2.89	0.48	16.6	0.224	7.7
Sept.	641.8	−325	316.8	0.197	0.305	0.089	0.138	2.17	0.34	15.7	0.154	7.1
Oct.	634.8	−104	530.8	0.189	0.293	0.145	0.224	2.53	0.34	13.4	0.258	10.2
Nov.	1 183.6	382	1 565.6	0.365	0.565	0.442	0.683	4.02	0.63	15.7	0.762	18.9
Dec.	2 361.3	543	2 904.3	0.704	1.090	0.794	1.229	4.95	1.25	25.2	1.414	29.2
Year	38 405.2	118	38 523.2	0.970	1.501	0.891	1.378	40.19	20.42	50.8	18.756	46.7

METROPOLITAN WATER WORKS, 1913.

Jan.	4 795.7	385	5 180.7	1.429	2.212	1.414	2.188	3.38	2.55	7.54	2.52	74.7
Feb.	2 628.4	241	2 869.4	0.868	1.343	0.867	1.341	2.55	1.40	54.9	1.40	54.7
Mar.	7 654.5	636	8 290.5	2.282	3.530	2.263	3.501	5.58	4.07	72.9	4.04	72.4
Apr.	7 228.1	159	7 387.1	2.226	3.445	2.083	3.223	3.90	3.84	98.5	3.60	92.2
May	3 934.8	−130	3 804.8	1.173	1.815	1.038	1.607	3.71	2.09	56.4	1.85	49.9
June	1 795.4	−803	992.4	0.553	0.856	0.280	0.433	0.90	0.96	106.7	0.48	38.8
July	687.1	−617	70.1	0.205	0.317	0.019	0.030	2.37	0.37	15.6	0.03	1.4
Aug.	630.8	−412	218.8	0.188	0.291	0.060	0.092	3.05	0.34	11.1	0.11	3.4
Sept.	722.1	53	775.1	0.222	0.344	0.219	0.338	4.44	0.38	8.6	0.38	8.5
Oct.	2 015.2	469	2 484.2	0.601	0.930	0.678	1.049	6.02	1.07	17.8	1.21	20.1
Nov.	2 283.9	56	2 339.9	0.704	1.090	0.660	1.021	2.59	1.21	46.7	1.14	43.9
Dec.	3 298.8	201	3 499.8	0.983	1.522	0.955	1.478	2.73	1.75	64.1	1.70	62.5
Year	37 674.8	238	37 912.8	0.953	1.476	0.879	1.360	41.22	20.03	48.6	18.46	44.8

METROPOLITAN WATER WORKS, 1914.

Total drainage area, 108.84 sq. miles. Area of land surface, 99.15 sq. miles.

Jan.	2 950	389	3 339	0.960	1.485	0.990	1.532	3.40	1.71	50.3	1.77	52.1
Feb.	3 190	409	3 599	1.149	1.778	1.181	1.827	3.58	1.85	51.7	1.90	53.1
Mar.	10 147	436	10 583	3.302	5.112	3.137	4.853	4.33	5.89	133.8	5.60	129.3
Apr.	8 140	327	8 467	2.738	4.236	2.593	4.012	4.91	4.72	96.2	4.48	91.2
May	5 978	−245	5 733	1.945	3.010	1.699	2.629	3.01	3.47	105.2	3.03	100.7
June	1 630	−595	1 035	0.548	0.849	0.317	0.490	2.00	1.06	52.8	0.55	27.4
July	1 454	−343	1 111	0.473	0.732	0.329	0.510	3.92	1.18	30.2	0.59	15.0

over the drainage area, by rain gages 14.853 in. in diameter, set with their tops about 12 in. above the ground. The depth of precipitation is determined by weight, one ounce representing, with gages of this size, a depth of 0.01 in. of precipitation. The snowfall is generally measured at smooth platforms level with the ground in places sheltered from the wind. A section of snow of the same diameter of the rain gage is collected and weighed to obtain the depth of precipitation. The conditions during the period under consideration have been very favorable for ascertaining accurately the yield from this drainage area.

METROPOLITAN WATER WORKS.

Sudbury River.

Information furnished by Dexter Brackett, chief engineer.

The records presented cover two dry periods, the first from 1879 to 1884, and the second from 1908 to February, 1912. As there was a material change in the conditions between these two periods, both will be described.

The following statements relate to the years 1908–1912:

The yield measured is that of the river above Dam No. 1, and that of Farm Pond, which is below the dam.

Drainage area, including water surfaces		75.20 sq. miles
Area of water surfaces of reservoirs, ponds, and streams	4.89	
A portion of the area of swamps reckoned as water surfaces as follows:		
30 per cent. of 1.47 sq. miles of drained swamps . . .	0.44	
40 per cent. of 5.69 sq. miles of undrained swamps . .	2.28	
Total area reckoned as water surfaces		7.61 sq. miles
Area of land (upland) surface		67.59 sq. miles

Full corrections are made for the water drawn from or added to storage except that no allowance is made for the storage in the ground surrounding the reservoirs.

There is no appreciable leakage or percolation into or out of the drainage area, but considerable water is diverted into and from it in connection with water supply and sewerage works.

Due allowance has been made for all of these diversions.

There are extensive flat areas occupied by swamps and reservoirs as above stated. Elsewhere the slopes are generally quite steep.

About one third of the area is forested. The woods are cleared from time to time but are allowed to grow up again.

The elevation above the sea ranges from 165 to about 500 ft., and averages about 300 ft.

During the years under consideration it has not been feasible to measure the amount of run-off from the Sudbury drainage area with the degree of accuracy attained before 1898. Before that

year the larger part of the water was measured through the aqueduct except during the spring when considerable water went over the spillways or through the waste gates at the lower dam.

Beginning in 1898, the greater part of the water used by the Metropolitan Water District has been drawn from the Wachusett reservoir into the Sudbury reservoir, and the water from the larger part of the Sudbury drainage area has been allowed to waste over the dams during the seasons of low flow as well as at other times, diminishing the accuracy of the measurement. Moreover, the unavoidable errors in the measurement of the large quantity of Wachusett water into and out of the Sudbury drainage area naturally affect the accuracy of the Sudbury records, especially at times of low flow. In 1898 the area of water surfaces of the Sudbury drainage area was greatly increased and the summer flow was consequently affected to a greater extent by evaporation. It is estimated that the total degree of error may average about five per cent.

The amount of precipitation is determined in the manner already described for the Wachusett drainage area, and the same number of gages are in use.

The following statements relate to the period 1879–1884:

During the years 1879–1880 measurements of the flow of the river were made at a temporary wooden dam below Dam No. 1.

Drainage area, including water surfaces		78.24 sq. miles
Area of water surfaces of reservoirs, ponds, and streams,	2.26	
40 per cent. of 7.34 sq. miles of undrained swamps . . .	2.94	
Total area reckoned as water surfaces		5.20 sq. miles
Area of land (upland) surface		73.04 sq. miles

At the beginning of the year 1881, the point of measurement was transferred from the temporary wooden dam to Dam No. 1 and the conditions were as follows:

Drainage area, including water surfaces	75.20 sq. miles
Total area reckoned as water surfaces as before	5.20 sq. miles
Area of land (upland) surface	70.00 sq. miles

METROPOLITAN WATER WORKS, 1879.

Yield of Sudbury River above Dam No. 1 and of Farm Pond. Total drainage area, 78.24 sq. miles. Area of land surface, 73.04 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	1 573.2	125	1 698.2	0.696	1.077	0.700	1.083	2.47	1.24	50.2	1.249	50.4
Feb.	3 526.9	221	3 747.9	1.724	2.670	1.711	2.647	3.56	2.78	78.1	2.756	77.4
Mar.	5 345.4	306	5 651.4	2.362	3.658	2.330	3.605	5.14	4.22	82.1	4.156	80.9
Apr.	7 162.7	151	7 313.7	3.270	5.062	3.116	4.821	4.71	5.64	119.8	5.379	114.1
May	2 934.4	−233	2 701.4	1.295	2.005	1.114	1.723	1.60	2.31	144.5	1.987	125.8
June	1 113.2	−143	970.2	0.508	0.786	0.413	0.640	3.79	0.88	23.2	0.713	18.8
July	548.7	−167	381.7	0.242	0.375	0.157	0.243	3.93	0.43	10.9	0.281	7.1
Aug.	875.3	83	958.3	0.386	0.598	0.395	0.611	6.51	0.69	10.6	0.705	10.8
Sept.	521.3	−191	330.3	0.238	0.368	0.141	0.218	1.88	0.41	21.8	0.243	12.9
Oct.	371.5	−200	171.5	0.164	0.254	0.071	0.109	0.81	0.29	35.8	0.126	15.6
Nov.	446.5	36	482.5	0.204	0.316	0.206	0.318	2.68	0.35	13.1	0.355	13.2
Dec.	874.8	247	1 121.8	0.386	0.598	0.463	0.716	4.34	0.69	15.9	0.825	19.0
Year	25 293.9	235	25 528.9	0.949	1.469	0.894	1.383	41.42	19.93	48.1	18.775	45.3

METROPOLITAN WATER WORKS, 1880.

Jan.	2 481.0	235	2 716.0	1.095	1.695	1.120	1.733	3.57	1.95	54.6	2.000	56.0
Feb.	3 790.4	264	4 054.4	1.871	2.899	1.787	2.765	3.98	2.99	75.1	2.982	74.9
Mar.	3 186.2	146	3 332.2	1.406	2.178	1.374	2.126	3.31	2.51	75.8	2.451	73.9
Apr.	2 731.0	12	2 743.0	1.247	1.931	1.169	1.808	3.10	2.15	69.4	2.017	65.0
May	1 483.0	−236	1 247.0	0.655	1.014	0.514	0.796	1.84	1.17	63.6	0.917	50.0
June	719.7	−308	411.7	0.329	0.509	0.175	0.271	2.14	0.57	26.6	0.303	14.2
July	401.7	26	427.7	0.177	0.274	0.176	0.273	6.27	0.32	5.1	0.315	5.0
Aug.	422.2	−134	288.2	0.186	0.288	0.119	0.184	4.01	0.33	8.2	0.212	5.3
Sept.	412.4	−224	188.4	0.188	0.291	0.080	0.124	1.60	0.32	20.0	0.138	8.6
Oct.	196.5	50	246.5	0.086	0.133	0.102	0.157	3.74	0.15	4.0	0.181	4.9
Nov.	521.7	−40	481.7	0.238	0.368	0.205	0.318	1.79	0.41	22.9	0.354	19.9
Dec.	311.8	113	424.8	0.138	0.214	0.175	0.271	2.83	0.25	8.8	0.312	11.1
Year	16 657.6	−96	16 561.6	0.650	1.006	0.578	0.895	38.18	13.12	34.4	12.182	31.9

METROPOLITAN WATER WORKS, 1881.

Total drainage area 75.2 sq. miles. Area of land surface, 70.0 sq. miles.

Jan.	568.9	398	966.9	0.262	0.405	0.415	0.642	5.56	0.47	8.5	0.740	13.3
Feb.	2 939.5	316	3 255.5	1.499	2.320	1.546	2.392	4.65	2.41	51.8	2.491	53.6
Mar.	8 971.6	362	9 333.6	4.133	6.400	4.004	6.195	5.73	7.37	128.6	7.142	124.6
Apr.	3 574.7	−87	3 487.7	1.702	2.635	1.546	2.392	2.00	2.94	147.0	2.669	133.4
May	2 331.6	−82	2 249.6	1.075	1.664	0.965	1.493	3.51	1.92	54.7	1.721	49.0
June	3 031.8	−14	3 017.8	1.444	2.234	1.338	2.070	5.39	2.49	46.2	2.309	42.8
July	971.3	−327	644.3	0.447	0.692	0.276	0.428	2.35	0.80	34.0	0.493	21.0
Aug.	715.2	−370	345.2	0.330	0.514	0.148	0.229	1.36	0.59	43.4	0.264	19.5
Sept.	574.9	−130	444.9	0.274	0.424	0.197	0.305	2.62	0.47	17.9	0.340	13.0
Oct.	449.6	−17	432.6	0.207	0.320	0.186	0.287	2.95	0.37	12.5	0.331	11.2
Nov.	733.0	158	891.0	0.349	0.540	0.395	0.611	4.09	0.60	14.7	0.682	16.7
Dec.	1 589.9	217	1 806.9	0.732	1.133	0.775	1.199	3.96	1.31	33.1	1.383	34.9
Year	26 452.0	424	26 870.0	1.035	1.602	0.979	1.515	44.17	21.74	49.3	20.565	46.6

METROPOLITAN WATER WORKS, 1882.

Jan.	2 447.2	445	2 892.2	1.127	1.745	1.241	1.920	5.95	2.01	33.8	2.213	37.2
Feb.	4 745.3	315	5 060.3	2.420	3.745	2.403	3.718	4.55	3.90	85.7	3.872	85.2
Mar.	6 532.9	85	6 617.9	3.011	4.662	2.839	4.392	2.65	5.37	202.8	5.064	191.2
Apr.	2 060.8	−104	1 956.8	0.982	1.519	0.867	1.342	1.82	1.69	92.8	1.497	82.1
May	2 956.9	54	3 010.9	1.362	2.109	1.292	1.998	5.06	2.43	48.0	2.304	45.5
June	1 544.3	−351	1 193.3	0.735	1.137	0.529	0.818	1.66	1.27	76.5	0.913	54.9
July	580.1	−379	201.1	0.268	0.415	0.086	0.133	1.77	0.48	27.1	0.154	8.7
Aug.	462.9	−334	128.9	0.213	0.330	0.055	0.086	1.67	0.38	22.8	0.099	5.9
Sept.	293.5	398	691.5	0.140	0.216	0.307	0.474	8.74	0.24	2.7	0.529	6.1
Oct.	793.7	−96	697.7	0.366	0.567	0.299	0.463	2.07	0.65	31.4	0.534	25.7
Nov.	568.3	−96	472.3	0.272	0.421	0.209	0.324	1.15	0.47	40.9	0.362	31.5
Dec.	663.6	70	733.6	0.306	0.474	0.315	0.487	2.30	0.55	23.9	0.561	24.5
Year	23 649.5	7	23 656.5	0.926	1.434	0.862	1.334	39.39	19.44	49.4	18.102	46.0

METROPOLITAN WATER WORKS, 1883.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area, Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	618.5	162	780.5	0.285	0.441	0.335	0.518	2.81	0.51	18.1	0.597	21.3
Feb.	1 927.4	247	2 174.4	0.984	1.522	1.033	1.598	3.86	1.58	40.9	1.664	43.1
Mar.	3 748.0	7	3 755.0	1.727	2.672	1.611	2.492	1.78	3.08	173.1	2.873	161.4
Apr.	3 147.5	−103	3 044.5	1.499	2.320	1.350	2.088	1.85	2.59	140.0	2.330	126.3
May	2 211.3	−26	2 185.3	1.019	1.578	0.937	1.450	4.18	1.82	43.5	1.673	40.0
June	959.9	−283	676.9	0.457	0.708	0.300	0.464	2.40	0.79	32.9	0.518	21.6
July	562.9	−294	268.9	0.260	0.402	0.115	0.178	2.68	0.46	17.2	0.206	7.7
Aug.	588.1	−405	183.1	0.271	0.420	0.079	0.122	0.74	0.48	64.8	0.140	19.1
Sept.	421.9	−216	205.9	0.201	0.310	0.091	0.141	1.52	0.35	23.0	0.157	10.4
Oct.	235.2	198	433.2	0.108	0.167	0.186	0.288	5.60	0.19	3.4	0.331	5.9
Nov.	496.7	−35	461.7	0.236	0.365	0.205	0.317	1.81	0.41	22.6	0.354	19.5
Dec.	293.1	158	451.1	0.135	0.209	0.194	0.299	3.55	0.24	6.8	0.345	9.7
Year	15 210.5	−590	14 620.5	0.595	0.922	0.533	0.824	32.78	12.50	38.1	11.188	34.1

METROPOLITAN WATER WORKS, 1884.

Jan.	1 967.9	352	2 319.9	0.907	1.403	0.995	1.540	5.08	1.62	31.8	1.77	34.8
Feb.	5 703.3	494	6 197.3	2.810	4.348	2.842	4.397	6.55	4.69	71.6	4.74	72.3
Mar.	8 552.3	272	8 824.3	3.941	6.098	3.785	5.857	4.72	7.04	149.2	6.75	143.0
Apr.	6 308.3	129	6 437.3	3.004	4.648	2.853	4.415	4.40	5.18	117.7	4.92	111.7
May	2 491.1	−89	2 402.1	1.148	1.776	1.030	1.594	3.47	2.05	59.1	1.84	53.0
June	1 129.0	−190	939.0	0.538	0.832	0.416	0.644	3.44	0.93	27.1	0.72	20.9
July	730.5	−209	521.5	0.337	0.521	0.224	0.346	3.67	0.60	16.3	0.40	10.9
Aug.	675.5	−77	598.5	0.311	0.481	0.257	0.397	4.65	0.55	11.8	0.46	9.9
Sept.	392.1	−293	99.1	0.187	0.289	0.044	0.068	0.86	0.32	37.2	0.08	9.4
Oct.	252.8	−59	193.8	0.117	0.181	0.083	0.129	2.48	0.21	8.5	0.15	6.0
Nov.	359.3	36	395.3	0.171	0.264	0.175	0.271	2.65	0.29	10.9	0.30	11.3
Dec.	1 829.0	327	2 156.0	0.843	1.304	0.925	1.431	5.17	1.50	29.0	1.65	31.9
Year	30 391.1	693	31 084.1	1.186	1.834	1.129	1.747	47.14	24.98	53.0	23.78	50.4

METROPOLITAN WATER WORKS, 1908.

Total drainage area, 75.20 sq. miles. Area of land surface, 67.59 sq. miles.

Jan.	4 143.6	344	4 487.6	1.979	3.062	1.925	2.978	3.60	3 53	98.1	3.434	95.4
Feb.	2 895.4	455	3 350.4	1.477	2.284	1.536	2.377	4.56	2.46	53.9	2.564	56.3
Mar.	4 985.7	276	5 261.7	2.379	3.680	2.257	3.492	3.82	4.24	111.0	4.026	105.5
Apr.	2 663.4	−143	2 520.4	1.315	2.034	1.117	1.729	1.88	2.27	120.8	1.929	102.6
May	2 300.5	137	2 437.5	1.099	1.701	1.046	1.618	5.51	1.96	35.6	1.865	33.9
June	1 052.6	−614	438.6	0.520	0.805	0.194	0.301	0.86	0.90	104.7	0.335	38.9
July	264.2	−297	−32.8	0.126	0.195	−0.014	−0.022	3.71	0.23	6.2	−0.025	−0.7
Aug.	358.7	−122	236.7	0.171	0.265	0.102	0.157	4.57	0.31	6.8	0.181	4.0
Sept.	227.5	−412	−184.5	0.112	0.173	−0.082	−0.127	0.97	0.19	19.6	−0.141	−14.5
Oct.	195.9	−87	108.9	0.094	0.145	0.047	0.072	2.55	0.17	6.7	0.083	3.3
Nov.	321.9	−162	159.9	0.159	0.246	0.071	0.110	0.98	0.27	27.6	0.122	12.5
Dec.	110.1	207	317.1	0.053	0.082	0.136	0.210	3.14	0.09	2.9	0.243	7.7
Year	19 519.5	−418	19 101.5	0.791	1.224	0.694	1.074	36.15	16.62	46.0	14.616	40.4

METROPOLITAN WATER WORKS, 1909.

Jan.	521.7	393	914.7	0.249	0.385	0.392	0.607	3.98	0.44	11.1	0.700	17.6
Feb.	4 197.0	617	4 814.0	2.218	3.430	2.286	3.537	5.79	3.57	61.7	3.684	63.6
Mar.	3 710.2	332	4 042.2	1.772	2.742	1.734	2.683	4.26	3.16	74.1	3.093	72.7
Apr.	3 659.9	222	3 881.9	1.805	2.793	1.721	2.662	4.67	3.11	66.6	2.970	63.6
May	2 605.9	−266	2 339.9	1.269	1.962	1.004	1.553	2.43	2.23	91.7	1.791	73.8
June	898.2	−358	540.2	0.443	0.686	0.239	0.370	2.81	0.77	27.4	0.413	14.7
July	292.8	−575	−282.2	0.140	0.217	−0.121	−0.187	1.59	0.25	15.7	−0.216	−13.5
Aug.	231.8	−336	−104.2	0.111	0.172	−0.045	−0.069	2.93	0.19	6.5	−0.080	−2.7
Sept.	254.2	82	336.2	0.126	0.195	0.149	0.231	4.74	0.22	4.6	0.257	5.4
Oct.	142.3	−262	−119.7	0.068	0.105	−0.051	−0.079	1.12	0.12	10.7	−0.092	−8.2
Nov.	39.6	146	185.6	0.020	0.031	0.082	0.127	3.38	0.03	0.9	0.142	4.2
Dec.	280.6	332	612.6	0.134	0.207	0.263	0.407	4.05	0.24	5.9	0.469	11.6
Year	16 834.2	327	17 161.2	0.682	1.055	0.625	0.967	41.75	14.33	34.3	13.131	31.5

METROPOLITAN WATER WORKS, 1910.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	2 888.6	584	3 472.6	1.378	2.133	1.490	2.305	5.39	2.46	45.6	2.657	49.3
Feb.	3 372.0	521	3 893.0	1.611	2.494	1.849	2.861	5.06	2.87	56.8	2.979	58.9
Mar.	4 666.2	−111	4 555.2	2.228	3.448	1.954	3.023	0.85	3.97	467.0	3.486	408.7
Apr.	1 522.0	−18	1 504.0	0.727	1.125	0.667	1.031	2.75	1.29	46.9	1.151	41.9
May	1 060.5	−414	646.5	0.507	0.785	0.277	0.429	1.29	0.90	69.8	0.495	38.3
June	1 277.8	−113	1 164.8	0.610	0.944	0.516	0.799	4.68	1.09	23.3	0.891	19.0
July	277.6	−516	−238.4	0.133	0.206	−0.102	−0.158	2.03	0.24	11.8	−0.182	−9.0
Aug.	207.5	−377	−169.5	0.099	0.153	−0.073	−0.113	2.62	0.18	6.9	−0.130	−5.0
Sept.	223.1	−212	11.1	0.107	0.166	0.005	0.008	2.49	0.19	7.6	0.008	0.3
Oct.	53.8	−172	−118.2	0.026	0.040	−0.051	−0.078	1.86	0.05	2.7	−0.091	−4.9
Nov.	152.7	245	397.7	0.073	0.113	0.176	0.273	4.13	0.13	3.1	0.304	7.4
Dec.	388.9	127	515.9	0.186	0.288	0.221	0.342	2.49	0.33	13.3	0.395	15.8
Year	16 090.7	−456	15 634.7	0.652	1.009	0.570	0.881	35.64	13.70	38.4	11.963	33.6

METROPOLITAN WATER WORKS, 1911.

Jan.	959.1	250	1 209.1	0.458	0.709	0.519	0.802	2.88	0.82	28.5	0.925	32.1
Feb.	1 250.8	224	1 474.8	0.661	1.022	0.700	1.084	2.77	1.07	38.6	1.128	40.7
Mar.	2 422.9	245	2 667.9	1.157	1.792	1.144	1.771	3.59	2.06	57.4	2.042	56.9
Apr.	3 237.3	−21	3 216.3	1.597	2.471	1.426	2.206	2.81	2.75	97.8	2.462	87.4
May	1 185.9	−445	740.9	0.568	0.879	0.318	0.492	1.01	1.01	100.0	0.567	56.1
June	862.1	−382	480.1	0.425	0.658	0.213	0.329	2.53	0.73	28.9	0.367	14.5
July	312.7	−346	−33.3	0.149	0.230	−0.014	−0.022	3.19	0.27	8.5	−0.025	−0.8
Aug.	117.5	−70	47.5	0.056	0.087	0.020	0.032	4.94	0.10	2.0	0.036	0.7
Sept.	337.5	−167	170.5	0.167	0.259	0.076	0.117	2.75	0.29	10.5	0.130	4.8
Oct.	626.1	64	690.1	0.299	0.463	0.296	0.458	3.69	0.53	14.4	0.528	14.3
Nov.	1 048.6	290	1 338.6	0.518	0.802	0.593	0.918	4.62	0.89	19.3	1.024	22.2
Dec.	1 856.4	261	2 117.4	0.886	1.371	0.908	1.405	3.60	1.58	43.9	1.620	45.0
Year	14 216.9	−97	14 119.9	0.577	0.893	0.514	0.796	38.38	12.10	31.5	10.804	28.2

METROPOLITAN WATER WORKS, 1912.

Jan.	1 446.4	251	1 697.4	0.681	1.054	0.728	1.127	2.94	1.20	40.7	1.299	44.1
Feb.	2 395.8	215	2 610.8	1.225	1.895	1.197	1.852	2.77	2.06	74.4	1.998	72.2

During the whole of this earlier period there was no appreciable leakage past the dams. Only a small quantity of water was diverted into and out of the drainage area by local water supplies, and no water was received from the Wachusett drainage area. In other respects, except for the building of additional storage reservoirs in the interval between the two periods, the conditions in each were substantially the same. On the whole, the conditions were much more favorable for accurate gaging in the earlier than in the later period.

METROPOLITAN WATER WORKS.

Lake Cochituate.

Information furnished by Dexter Brackett, chief engineer.

The records cover two dry periods, the first from 1879 to January, 1884, and the second from 1908 to 1912. The conditions changed but little between these two periods.

The yield measured is that at the outlet of the lake.

Drainage area, including water surfaces during the years 1879–1884 and 1908 and 1909		18.87 sq. miles
Area of water surfaces of reservoirs, ponds, and streams,	1.38	
40 per cent. of 0.93 sq. miles of undrained swamps . .	0.37	
Total area reckoned as water surfaces		1.75 sq. miles
Area of land (upland) surface		17.12 sq. miles

Full corrections are made for the water drained from or added to visible storage, but no allowance is made for a considerable amount of storage in the porous ground surrounding the lake.

There is some percolation from the lake where it is retained by natural sandy barriers, which is much larger when the lake is full than when it is drawn down. No allowance has been made for this percolation in the computations, but the resulting error is probably not more than two per cent.

During the period 1908–1912, considerable water was diverted into and from the drainage area in connection with water supply and sewerage works, for which due allowance has been made in the computations.

During the earlier period the water so diverted was a small quantity and no account was taken of it.

In 1910 the drainage area was diminished by the diversion in another direction of the flow from Dug Pond and its tributary area, reducing the drainage area, including water surfaces, to 17.8 sq. miles and the land surface to 16.12 sq. miles.

At the beginning of 1911, the construction of a drain to remove polluted water resulted in a further reduction of the drainage area of the lake, including water surfaces, to 17.58 sq. miles, and a corresponding reduction in the land surface to 15.90 sq. miles.

Most of the drainage area is nearly level or with gentle slopes, and but a small part of it is hilly.

The soil is sand and gravel; rather less than one third is forested and the remainder is cultivated or pasture land or is occupied by the towns upon the drainage area.

The elevation above the sea ranges from 140 to 300 ft. and averages about 180 ft.

During the earlier period water was discharged from the Sudbury River into Lake Cochituate to the extent of about 14 per cent. of the yield of the latter. This quantity was carefully measured before it entered the lake.

During the later period there was no such diversion.

The records of the earlier period were used only for determining the relative yield during the two periods, and are not reproduced here.

METROPOLITAN WATER WORKS, 1908.

Yield of Lake Cochituate. Total drainage area, 18.87 sq. miles. Area of land surface, 17.12 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	702.7	72.1	774.8	1.324	2.049	1.325	2.049	3.33	2.36	71.0	2.36	71.0
Feb.	754.4	98.8	853.2	1.519	2.351	1.559	2.412	4.30	2.53	58.8	2.60	60.5
Mar.	1 055.5	58.4	1 113.9	1.989	3.077	1.904	2.946	3.62	3.55	98.1	3.49	96.8
Apr.	594.8	−35.6	559.2	1.158	1.792	0.988	1.528	1.80	2.00	111.1	1.71	94.7
May	499.8	3.6	503.4	0.942	1.457	0.861	1.331	4.58	1.68	36.7	1.53	33.5
June	129.6	−14.4	115.2	0.252	0.390	0.203	0.315	0.82	0.44	53.5	0.35	42.8
July	154.7	−62.2	92.5	0.291	0.451	0.158	0.245	3.91	0.52	13.3	0.28	7.2
Aug.	115.1	−45.4	69.7	0.217	0.336	0.119	0.184	3.98	0.39	9.8	0.21	5.3
Sept.	89.3	−100.1	−10.8	0.174	0.269	−0.019	−0.030	0.77	0.30	39.0	−0.03	−4.3
Oct.	64.5	−23.6	40.9	0.122	0.188	0.070	0.108	2.37	0.22	9.3	0.12	5.3
Nov.	86.5	−41.6	44.9	0.168	0.261	0.079	0.123	0.85	0.29	34.1	0.14	16.1
Dec.	111.3	35.2	146.5	0.210	0.324	0.250	0.387	2.70	0.37	13.7	0.45	16.5
Year	4 358.2	−54.8	4 303.4	0.696	1.076	0.623	0.964	33.03	14.65	44.4	13.12	39.7

METROPOLITAN WATER WORKS, 1909.

Jan.	139.1	100.4	239.5	0.262	0.406	0.409	0.633	4.34	0.47	10.8	0.73	16.8
Feb.	951.2	138.6	1 089.8	1.984	3.070	2.063	3.191	5.66	3.20	56.5	3.32	58.7
Mar.	734.1	69.3	803.4	1.383	2.140	1.373	2.125	3.98	2.47	62.1	2.45	61.5
Apr.	738.4	46.5	784.9	1.438	2.224	1.387	2.145	4.50	2.48	55.1	2.39	53.2
May	533.8	−73.3	460.5	1.006	1.556	0.787	1.218	2.05	1.79	87.3	1.40	68.5
June	292.8	−74.1	218.7	0.570	0.882	0.386	0.598	3.09	0.98	31.7	0.67	21.6
July	193.9	−125.6	68.3	0.365	0.565	0.117	0.181	1.73	0.65	37.6	0.21	12.0
Aug.	239.7	−76.3	163.4	0.452	0.699	0.279	0.432	2.84	0.81	28.5	0.50	17.5
Sept.	235.2	5.6	240.8	0.458	0.709	0.425	0.658	4.33	0.79	18.2	0.74	17.0
Oct.	108.2	−54.4	53.8	0.204	0.316	0.092	0.142	1.06	0.36	34.0	0.16	15.5
Nov.	95.4	40.9	136.3	0.186	0.287	0.241	0.373	3.76	0.32	8.5	0.42	11.1
Dec.	138.3	72.5	210.8	0.261	0.403	0.360	0.558	4.10	0.47	11.5	0.64	15.7
Year	4 400.1	70.1	4 470.2	0.704	1.089	0.649	1.004	41.44	14.79	35.7	13.63	32.9

METROPOLITAN WATER WORKS, 1910.

Total drainage area, 17.8 sq. miles. Area of land surface, 16.12 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	748.3	116.1	864.4	1.497	2.317	1.567	2.424	5.11	2.67	52.2	2.80	54.7
Feb.	785.5	118.6	904.1	1.740	2.693	1.814	2.807	5.16	2.81	54.4	2.92	56.7
Mar.	886.9	−26.8	860.1	1.775	2.746	1.559	2.412	0.77	3.17	411.6	2.78	361.1
Apr.	403.2	−7.4	395.8	0.834	1.290	0.741	1.147	2.71	1.44	53.1	1.28	47.2
May	303.1	−88.1	215.0	0.607	0.938	0.390	0.603	1.33	1.08	81.2	0.70	52.3
June	382.0	−28.6	353.4	0.790	1.222	0.662	1.024	4.51	1.36	30.2	1.14	25.3
July	193.3	−103.6	89.7	0.387	0.598	0.163	0.252	2.23	0.69	30.9	0.29	13.0
Aug.	113.1	−108.3	4.8	0.226	0.350	0.009	0.013	1.58	0.40	25.3	0.02	1.0
Sept.	79.6	−44.8	34.8	0.165	0.255	0.065	0.101	2.50	0.28	11.2	0.11	4.5
Oct.	50.1	−37.6	12.5	0.100	0.155	0.023	0.035	1.80	0.18	10.0	0.04	2.2
Nov.	77.6	53.1	130.7	0.160	0.248	0.245	0.379	4.16	0.28	6.7	0.42	10.2
Dec.	149.8	30.8	180.6	0.300	0.464	0.327	0.506	2.61	0.54	20.7	0.58	22.4
Year	4 172.5	− 126.6	4 045.9	0.709	1.097	0.623	0.964	34.47	14.90	43.2	13.08	37.9

METROPOLITAN WATER WORKS, 1911.

Total drainage area, 17.58 sq. miles. Area of land surface, 15.90 sq. miles.

Jan.	221.6	50.4	272.0	0.450	0.696	0.497	0.768	2.74	0.80	29.2	0.89	32.3
Feb.	311.6	61.7	373.3	0.700	1.083	0.758	1.173	3.20	1.13	35.3	1.22	38.2
Mar.	565.2	46.4	611.6	1.147	1.774	1.122	1.736	3.31	2.05	61.9	2.00	60.5
Apr.	669.4	−7.0	662.4	1.403	2.171	1.256	1.943	2.73	2.42	88.6	2.17	79.4
May	199.5	−111.2	88.3	0.405	0.626	0.162	0.251	0.65	0.72	110.8	0.29	44.5
June	127.6	−87.9	39.7	0.268	0.414	0.075	0.116	2.53	0.46	18.2	0.13	5.1
July	91.7	−73.4	18.3	0.186	0.288	0.034	0.052	3.42	0.33	9.6	0.06	1.8
Aug.	190.3	−18.9	171.4	0.386	0.597	0.315	0.487	4.82	0.69	14.3	0.56	11.6
Sept.	217.8	−30.6	187.2	0.457	0.706	0.355	0.549	2.96	0.79	26.7	0.61	20.7
Oct.	267.7	9.1	276.8	0.543	0.840	0.508	0.786	3.53	0.97	27.5	0.91	25.7
Nov.	312.1	51.9	364.0	0.654	1.012	0.690	1.068	4.28	1.12	26.2	1.19	27.8
Dec.	487.7	60.8	548.5	0.989	1.531	1.006	1.557	3.74	1.77	47.3	1.79	46.4
Year	3 662.2	−48.7	3 613.5	0.631	0.976	0.563	0.871	37.91	13.25	35.0	11.82	31.2

METROPOLITAN WATER WORKS, 1912.

Jan.	285.2	60.2	345.4	0.579	0.895	0.634	0.981	3.10	1.03	33.2	1.13	36.5
Feb.	545.5	41.9	587.4	1.183	1.830	1.152	1.783	2.51	1.98	78.9	1.92	76.6
Mar.	1 365.5	135.8	1 501.3	2.770	4.286	2.755	4.262	6.38	4.94	77.4	4.91	77.0
Apr.	996.5	34.7	1 031.2	2.089	3.232	1.955	3.025	4.16	3.61	86.8	3.38	81.1
May	768.1	22.5	790.6	1.558	2.411	1.451	2.245	5.23	2.78	53.2	2.59	49.5
June	290.2	−148.0	142.2	0.608	0.941	0.270	0.417	0.47	1.05	223.4	0.46	99.0
July	108.4	−86.5	21.9	0.220	0.340	0.040	0.062	3.00	0 39	13.0	0.07	2.4
Aug.	135.1	−93.5	41.6	0.274	0.424	0.076	0.118	2.26	0.49	21.7	0.14	6.0
Sept.	185.2	−65.6	119.6	0.388	0.601	0.227	0.351	1.82	0.67	36.8	0.39	21.5
Oct.	154.5	−4.8	149.7	0.313	0.485	0.275	0.425	2.99	0.56	18.7	0.49	16.4
Nov.	148.5	27.5	176.0	0.311	0.482	0.334	0.516	3.24	0.54	16.7	0.58	17.8
Dec.	238.5	97.1	335.6	0.484	0.749	0.616	0.953	4.96	0.86	17.3	1.10	22.1
Year	5 221.2	21.3	5 242.5	0.897	1.388	0.815	1.261	40.12	18.90	47.1	17.16	42.77

The discharge measurements are believed to be fairly accurate.

The precipitation is measured by a single gage at the lake of the same kind that is used on the Wachusett and Sudbury drainage areas.

SPRINGFIELD, MASS., WATER WORKS.

Westfield Little River.

Information furnished by E. E. Lochridge, chief engineer.

The yield for 1910 and 1911 was measured at the intake dam of the Springfield Water Works; in 1908 and 1909 it was measured at a point further upstream.

The records are for the years 1908–1911.

1908 and 1909:

Drainage area, including water surfaces	43.00 sq. miles.
Area of water surfaces (3 ponds)	0.35 sq. miles.
Area of land surface	42.65 sq. miles.

1910 and 1911:

Drainage area, including water surfaces	48.00 sq. miles.
Area of water surfaces	0.69 sq. miles.
Area of land surface	47.31 sq. miles.

Borden Brook Reservoir was first filled in 1910, which accounts for the changed area of water surfaces.

There are no drained swamps. Swamps of any type are high level and many of them with steep sides.

In 1908–1909 no corrections were made for the water drawn from or added to storage. In 1910–1911 corrections were made for the water drawn from or added to storage in the Borden Brook Reservoir, but not in other ponds. No allowance is made for the invisible storage in the ground about the reservoir, and there is none as far as can be ascertained.

The drainage area is steep, rocky, and perhaps three fourths forested.

The elevation above the sea varies from 500 to 1 750 ft.

The discharge in 1910–1911, at times when all of the water was used for water supply purposes, was measured by a Venturi meter, and when wasting over the dam was measured also by weir on which accurate coefficients have been established by the Testing Station of Cornell University at Ithaca, N. Y.

The precipitation is measured by United States Geological Survey standard gage. Depth of snowfall is measured in several places; a sample collected of average depth and melted.

SPRINGFIELD, MASS., WATER WORKS, 1908.
Yield of Westfield Little River. Total drainage area, 43 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.
January	3 290	2.47	3.84	1.79	4.43	247.5
February	2 630	2.11	3.28	5.67	3.54	62.4
March	5 820	4.36	6.79	1.92	7.83	407.8
April	2 590	2.01	3.12	4.08	3.48	85.2
May	3 590	2.70	4.19	6.67	4.83	72.4
June	530	0.41	0.64	3.43	0.71	20.7
July	375	0.28	0.44	5.13	0.50	9.8
August	281	0.21	0.33	4.42	0.38	8.6
September	110	0.08	0.13	1.43	0.15	10.5
October	200	0.15	0.23	2.25	0.27	12.0
November	227	0.18	0.27	0.40	0.31	77.5
December	710	0.53	0.83	3.43	0.95	27.7
The Year	20 353	1:30	2.01	40.62	27.38	67.4

SPRINGFIELD, MASS., WATER WORKS, 1909.

January	1 590	1.20	1.85	4.67	2.13	45.6
February	4 140	3.45	5.35	5.42	5.57	102.8
March	3 730	2.80	4.35	3.40	5.02	147.6
April	4 980	3.86	6.00	6.67	6.69	100.3
May	2 070	1.56	2.42	2.87	2.79	97.3
June	564	0.44	0.68	2.30	0.76	33.1
July	158	0.12	0.18	2.15	0.21	9.8
August	265	0.20	0.31	5.54	0.36	6.5
September	181	0.14	0.22	4.08	0.24	5.9
October	202	0.15	0.24	1.16	0.27	23.3
November	222	0.17	0.27	2.37	0.30	12.7
December	935	0.70	1.09	4.64	1.26	27.2
The Year	19 037	1.23	1.91	45.27	25.30	55.8

SPRINGFIELD, MASS., WATER WORKS, 1910.
Total drainage area, 48 sq. miles.

January	2 990	2.01	3.12	3.22	3.60	112.0
February	2 910	2.17	3.37	4.90	3.51	71.6
March	5 040	3.39	5.25	0.80	6.05	756.0
April	2 480	1.72	2.66	4.37	2.97	68.0
May	936	0.63	0.98	4.10	1.13	27.6
June	1 800	1.25	1.94	3.88	2.16	55.9
July	246	0.17	0.26	0.42	0.30	71.5
August	245	0.17	0.26	4.83	0.30	6.2
September	158	0.11	0.17	2.99	0.19	6.4
October	34	0.02	0.03	0.96	0.03	3.1
November	757	0.53	0.82	6.25	0.92	14.7
December	309	0.21	0.33	2.62	0.38	14.5
The Year	17 905	1.03	1.60	39.34	21.54	54.8

SPRINGFIELD, MASS., WATER WORKS, 1911.

January	1 000	0.67	1.04	1.17	1.20	102.0
February	382	0.28	0.43	2.26	0.45	19.9
March	1 860	1.25	1.94	4.39	2.24	51.0
April	3 580	2.49	3.86	2.74	4.31	157.0
May	1 250	0.84	1.30	2.07	1.50	72.5
June	1 530	1.06	1.64	4.17	1.83	43.8
July	318	0.21	0.33	3.46	0.38	11.0
August	478	0.32	0.50	6.60	0.58	8.8
September	1 220	0.84	1.30	5.32	1.45	27.3
October	4 970	3.34	5.18	8.99	5.97	66.4
November	2 580	1.79	2.77	3.77	3.09	81.9
December	2 260	1.52	2.35	3.44	2.71	78.8
The Year	21 428	1.22	1.89	48.38	25.71	53.1

WESTFIELD, MASS., WATER WORKS.

Tillotson Brook.

Information furnished by John L. Hyde, town engineer.

The yield of Tillotson Brook is measured below the junction with Hollister Brook in Granville, Mass.

The records are for the years 1908–1911.

Drainage area, which includes practically no water surfaces or swamps, 5.84 sq. miles. A small intake reservoir has an area of only about one acre.

There is apparently no leakage into or out of the drainage area to affect the records.

The drainage area is about 80 per cent. forested. The soil is gravel and rocks, with very little loam.

The elevation above the sea ranges from about 550 to 1 500 ft., and averages about 990 ft.

The discharge measurements were made at a weir, and heights were read twice each day by the use of a hook gage.

Records of precipitation were obtained from a standard rain gage 8 in. in diameter, located near the gaging station. The snow is melted and water measured. Judging from experience elsewhere, the average precipitation on the drainage area would be greater than that recorded, because of the higher elevation of a portion of the area.

WESTFIELD WATER WORKS, 1908.

Yield of Tillotson Brook. Total drainage area (all land surface), 5.84 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.
January	235.714	1.302	2.015	3.05	2.32	76.15
February	272.669	1.510	2.491	5.82	2.69	46.16
March	501.118	2.768	4.283	3.05	4.94	161.89
April	291.007	1.661	2.570	3.26	2.87	87.96
May	364.433	2.013	3.115	6.42	3.59	55.93
June	124.216	0.709	1.097	2.27	1.22	53.92
July	81.830	0.452	0.699	4.11	0.80	19.61
August	85.269	0.471	0.729	5.02	0.84	16.73
September	32.937	0.188	0.290	1.63	0.32	19.91
October	53.044	0.293	0.453	3.02	0.52	17.30
November	42.924	0.245	0.379	0.83	0.42	50.95
December	72.234	0.399	0.617	2.95	0.71	24.13
The Year	2 157.395	1.009	1.561	41.43	21.24	51.26

WESTFIELD WATER WORKS, 1909.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.
January	139.406	0.770	1.911	4.06	1.37	33.81
February	267.191	1.634	2.528	6.23	2.63	42.26
March	452.238	2.498	3.865	4.76	4.46	93.62
April	521.495	2.976	4.604	6.38	5.14	80.54
May	294.552	1.627	2.517	3.45	2.90	84.12
June	117.033	0.668	1.033	2.26	1.15	51.02
July	40.552	0.224	0.346	2.19	0.40	18.25
August	88.709	0.490	0.758	6.28	0.87	13.92
September	43.975	0.251	0.388	3.80	0.43	11.40
October	39.828	0.220	0.340	1.22	0.39	32.17
November	43.800	0.250	0.387	2.73	0.43	15.80
December	86.718	0.479	0.741	3.90	0.85	21.91
The Year	2 135.497	1.007	1.618	47.26	21.02	44.47

WESTFIELD WATER WORKS, 1910.

January	275.724	1.523	2.356	6.40	2.72	42.45
Feburary	227.456	1.391	2.152	4.98	2.24	45.00
March	582.043	3.215	4.974	1.48	5.73	387.52
April	337.610	1.927	2.981	4.79	3.33	69.45
May	194.336	1.074	1.661	3.25	1.91	58.92
June	183.609	1.048	1.621	4.08	1.81	44.34
July	36.751	0.203	0.314	1.29	0.36	28.09
August	33.311	0.184	0.284	3.58	0.33	9.17
September	37.843	0.216	0.334	4.08	0.37	9.14
October	26.613	0.147	0.226	1.01	0.26	25.96
November	94.433	0.539	0.834	5.12	0.92	18.17
December	119.486	0.660	1.021	1.78	1.18	66.14
The Year	2 149.215	1.011	1.563	41.84	21.16	50.57

WESTFIELD WATER WORKS, 1911.

January	69.198	0.383	0.593	2.06	0.68	33.09
February	64.590	0.395	0.611	2.09	0.64	30.45
March	278.983	1.541	2.384	3.31	2.75	83.05
April	299.767	1.711	2.647	2.55	2.95	115.83
May	83.096	0.459	0.710	1.15	0.82	71.20
June	101.090	0.577	0.892	4.01	1.00	24.84
July	26.613	0.147	0.227	4.40	0.25	5.73
August	64.631	0.357	0.552	6.94	0.64	9.17
September	91.554	0.522	0.807	4.95	0.90	18.22
October	326.777	1.805	2.793	10.10	3.22	31.88
November	187.639	1.701	1.657	3.00	1.85	61.63
December	261.603	1.445	2.236	3.44	2.58	74.93
The Year	1 855.541	0.868	1.342	48.00	18.28	38.08

WORCESTER, MASS., WATER WORKS.

Tatnuck Brook.

Information furnished by Frederick A. McClure, city engineer.

The yield is measured at the lowest water-works dam, and the records cover the years 1908–February, 1912.

Drainage area, including water surfaces		5.231 sq. miles
Area of water surfaces	0.285	
A portion of the area of swamps reckoned as water surfaces as follows:		
30 per cent. of 0.020 sq. miles of drained swamps .	0.006	
40 per cent. of 0.066 sq. miles of undrained swamps	0.026	
Total area reckoned as water surfaces		0.317 sq. miles
Area of land (upland) surface		4.914 sq. miles

Full corrections are made for the water drained from or added to storage except that no allowance is made for storage in the ground surrounding the reservoirs.

There is no appreciable leakage from the reservoirs, but beginning in August, 1911, some water was diverted into this area from

WORCESTER, MASS., WATER WORKS, 1908.

Yield of Tatnuck Brook. Total drainage area, 5.231 sq. miles. Area of land surface, 4.914 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	....	....	....	....	....	....	....	2.98	....	....	....	....
Feb.	....	....	....	....	....	....	....	5.01	....	....	....	....
Mar.	....	....	....	....	....	....	....	3.34	....	....	....	....
Apr.	....	....	....	....	....	....	....	2.40	....	....	....	....
May	....	....	....	....	....	....	....	4.33	....	....	....	....
June	86.3	−21.6	64.7	0.586	0.90	0.412	0.63	1.72	1.00	58.2	0.71	41
July	48.3	−6.0	42.3	0.317	0.48	0.261	0.40	4.91	0.55	11.2	0.46	9
Aug.	58.6	5.2	63.8	0.384	0.59	0.393	0.60	6.47	0.68	10.5	0.70	11
Sept.	25.4	−13.9	11.5	0.172	0.26	0.073	0.11	1.52	0.30	19.7	0.12	8
Oct.	36.2	−6.4	29.8	0.237	0.36	0.184	0.28	1.92	0.42	21.9	0.32	17
Nov.	43.3	−6.0	37.3	0.292	0.45	0.238	0.36	1.05	0.50	47.6	0.41	39
Dec.	60.7	8.8	69.5	0.330	0.51	0.429	0.66	3.34	0.59	17.7	0.76	23
Year	2 310.9	−3.3	2 307.6	1.277	1.90	1.205	1.86	38.99	26.87	68.9	25.38	65

WORCESTER, MASS., WATER WORKS, 1909.

Jan.	78.8	9.6	88.4	0.513	0.79	0.545	0.84	2.98	0.91	30.5	0.97	33
Feb.	398.5	27.1	425.6	2.882	4.46	2.906	4.49	6.36	4.64	73.0	4.68	73
Mar.	404.0	14.4	418.4	2.651	4.10	2.580	3.99	4.31	4.73	109.8	4.60	106
Apr.	534.3	19.9	554.2	3.630	5.61	3.531	5.46	6.48	6.26	96.6	6.09	94
May	249.9	−11.1	238.8	1.645	2.54	1.472	2.27	2.54	2.93	115.4	2.62	103
June	71.9	−15.3	56.6	0.489	0.75	0.361	0.55	2.84	0.84	29.6	0.62	22
July	20.9	−20.5	0.4	0.137	0.21	0.003	0.004	2.19	0.24	11.0	0.0049	0.2
Aug.	38.7	−10.8	27.9	0.253	0.39	0.172	0.26	3.39	0.45	13.3	0.30	9
Sept.	37.0	−0.9	36.1	0.249	0.38	0.230	0.35	3.94	0.42	10.7	0.39	10
Oct.	31.6	−6.3	25.3	0.205	0.31	0.156	0.24	1.75	0.36	20.6	0.27	16
Nov.	44.3	−0.9	43.4	0.296	0.45	0.277	0.42	2.04	0.50	24.5	0.47	23
Dec.	69.9	5.6	75.5	0.451	0.69	0.465	0.72	3.64	0.80	22.0	0.83	23
Year	1 979.8	10.8	1 990.6	1.098	1.70	1.043	1.61	42.46	23.08	54.4	22.20	52

WORCESTER, MASS., WATER WORKS, 1910.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	303.8	19.7	323.5	1.962	3.03	1.995	3.078	5.77	3.49	60.5	3.55	61
Feb.	319.5	13.7	333.2	2.299	3.55	2.275	3.519	3.98	3.70	92.9	3.66	92
Mar.	475.9	−1.3	474.6	3.117	4.82	2.927	4.529	1.46	5.56	381.0	5.22	357
Apr.	187.1	3.5	190.6	1.270	1.96	1.215	1.879	3.61	2.19	60.8	2.09	58
May	119.6	−14.9	104.7	0.785	1.21	0.646	0.999	1.75	1.39	79.4	1.15	66
June	139.8	−15.9	123.9	0.946	1.46	0.789	1.221	2.48	1.63	65.7	1.36	55
July	27.4	−20.4	7.0	0.179	0.27	0.043	0.066	1.82	0.31	17.0	0.07	4
Aug.	39.1	−4.9	34.2	0.254	0.39	0.211	0.326	4.39	0.45	10.3	0.37	8
Sept.	28.8	−3.8	25.0	0.192	0.29	0.159	0.246	3.19	0.32	10.0	0.27	8
Oct.	27.7	−6.7	21.0	0.179	0.27	0.154	0.200	1.29	0.31	24.0	0.23	17
Nov.	49.0	6.5	55.5	0.324	0.50	0.354	0.547	4.23	0.56	13.2	0.61	14
Dec.	73.9	3.4	77.3	0.472	0.73	0.477	0.737	2.66	0.84	31.6	0.85	32
Year	1 791.6	−21.1	1 770.5	0.988	1.52	0.927	1.445	36.63	20.75	56.6	19.47	53

WORCESTER, MASS., WATER WORKS, 1911.

Jan.	149.6	6.1	155.7	0.953	1.47	0.960	1.485	3.03	1.70	56.1	1.71	56
Feb.	113.9	3.6	117.5	0.774	1.19	0.803	1.242	2.38	1.24	52.1	1.29	54
Mar.	257.5	7.2	264.7	1.642	2.54	1.633	2.526	4.09	2.93	71.6	2.91	71
Apr.	316.0	−2.4	313.6	2.096	3.24	1.998	3.092	2.29	3.62	158.0	3.45	150
May	132.2	−9.0	123.2	0.851	1.31	0.760	1.175	2.06	1.51	73.3	1.35	65
June	87.3	−10.9	76.4	0.578	0.89	0.487	0.752	2.35	0.99	42.1	0.84	36
July	42.1	−7.4	34.7	0.268	0.41	0.214	0.331	3.23	0.47	14.6	0.38	12
Aug.	38.7	−0.2	38.5	0.245	0.38	0.237	0.367	5.40	0.44	8.2	0.42	7
Sept.	50.2	0	50.2	0.328	0.50	0.320	0.495	4.11	0.56	13.6	0.55	13
Oct.	163.7	6.6	170.3	1.041	1.61	1.050	1.624	5.53	1.85	33.5	1.87	33
Nov.	212.8	9.2	222.0	1.417	2.19	1.414	2.188	4.60	2.44	53.0	2.44	53
Dec.	213.3	7.4	220.7	1.384	2.14	1.361	2.106	3.17	2.47	77.9	2.43	76
Year	1 777.3	10.2	1 787.5	0.964	1.49	0.936	1.448	42.24	20.22	47.9	19.66	46

WORCESTER, MASS., WATER WORKS, 1912.

Jan.	150.8	6.0	156.8	0.977	1.51	0.967	1.49	2.34	1.74	74.4	1.72	73
Feb.	149.6	7.1	156.7	1.074	1.66	1.033	1.59	2.67	1.79	67.0	1.72	64

a portion of the Wachusett drainage area, and due allowance has been made in the computations therefor.

The drainage area consists of rugged hills and steep slopes with clayey subsoil and stony fields with small area of gravel deposits. From 50 to 60 per cent. of the area is forested, as near as can be estimated.

The elevation above the sea ranges from 720 to 1 400 ft. and averages about 950 ft.

The precipitation is measured by an 8-in standard gage near the lowest reservoir dam.

PAWTUCKET, R. I., WATER WORKS.

Abbott Run.

Information furnished by George A. Carpenter, city engineer.

The records presented give the yield of Abbott Run at Cumberland Mills, R. I., for the years 1908–1912.

Drainage area, including water surfaces	26.94 sq. miles
Area of water surfaces	0.75 sq. miles
Area of land surface	26.19 sq. miles

There are no swampy areas of any material size.

Corrections are made for the water drawn from or added to storage in the reservoir, which has an area of 0.58 sq. miles. There is no percolation or leakage or diversion of water to materially affect the records.

The drainage area is covered with small farms, fertile valleys, and somewhat steep hillsides. Outcroppings of ledge occur in many locations. The area is not heavily wooded.

The elevation above the sea varies from 48 to from 300 to 400 ft., and averages about 150 ft.

The discharge is measured over a steel crested weir 54.92 ft. long, and the run-off computed by the Francis weir formula.

The precipitation is collected in a rain gage 14.853 in. in diameter and weighed, each ounce in weight being equal to 0.01 in. in depth. Snowfall is melted and weighed.

PAWTUCKET, R. I., WATER WORKS, 1908.

Yield of Abbott Run. Total drainage area, 26.94 sq. miles. Area of land surface, 26.19 sq. miles

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land surface.		Total area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	1 635.7	41.4	1 677.1	2.015	3.117	2.008	3.107	4.14	3.59	86.8	3.58	86.5
Feb.	1 872.7	54.3	1 927.0	2.554	3.951	2.555	3.953	5.22	4.12	79.0	4.12	78.9
Mar.	1 892.9	33.8	1 926.7	2.331	3.607	2.307	3.569	4.30	4.16	96.9	4.11	95.6
Apr.	985.0	−8.3	976.7	1.254	1.940	1.209	1.870	2.33	2.16	92.8	2.09	89.7
May	940.7	14.8	955.5	1.159	1.793	1.144	1.770	5.60	2.06	36.8	2.04	36.4
June	547.1	−53.4	493.7	0.696	1.077	0.611	0.945	1.44	1.20	83.5	1.05	72.9
July	381.3	14.3	395.6	0.470	0.726	0.474	0.733	7.08	0.84	11.9	0.84	11.9
Aug.	277.1	−12.2	264.9	0.341	0.528	0.317	0.491	4.56	0.61	13.4	0.57	12.5
Sept.	155.2	−41.5	113.7	0.197	0.306	0.141	0.218	0.93	0.34	36.6	0.24	25.8
Oct.	148.5	4.7	153.2	0.183	0.283	0.183	0.284	3.52	0.33	9.4	0.33	9.4
Nov.	198.3	−18.0	180.3	0.252	0.391	0.223	0.345	0.87	0.44	50.5	0.39	44.8
Dec.	420.2	16.5	436.7	0.518	0.801	0.523	0.809	2.78	0.92	33.1	0.93	33.5
Year	9 454.7	46.4	9 501.1	0.986	1.530	0.964	1.495	42.77	20.77	48.6	20.29	47.4

PAWTUCKET, R. I., WATER WORKS, 1909.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	482.9	27.4	510.3	0.595	0.920	0.611	0.945	3.07	1.06	34.6	1.09	35.5
Feb.	1 878.3	67.7	1 946.9	2.561	3.963	2.580	3.992	6.25	4.12	66.0	4.17	66.7
Mar.	1 585.7	26.4	1 612.1	1.953	3.022	1.930	2.987	3.73	3.48	93.4	3.44	92.2
Apr.	1 451.7	30.8	1 482.5	1.848	2.859	1.835	2.838	5.34	3.19	59.8	3.17	59.4
May	1 145.9	−35.9	1 110.0	1.411	2.184	1.329	2.056	1.70	2.52	148.2	2.37	139.4
June	438.4	−38.3	400.1	0.558	0.863	0.495	0.766	2.60	0.96	36.9	0.85	32.7
July	154.1	−54.4	99.7	0.190	0.294	0.119	0.185	1.80	0.34	18.9	0.21	11.7
Aug.	110.5	−45.4	65.1	0.136	0.211	0.078	0.121	2.01	0.24	11.9	0.14	7.0
Sept.	95.4	2.5	97.9	0.121	0.188	0.121	0.187	4.31	0.21	4.9	0.21	4.9
Oct.	136.0	−24.7	111.3	0.168	0.259	0.133	0.206	1.26	0.30	23.8	0.24	19.0
Nov.	213.2	19.8	233.0	0.271	0.420	0.288	0.446	3.77	0.47	12.5	0.50	13.3
Dec.	280.3	39.6	319.9	0.345	0.534	0.383	0.593	4.55	0.62	13.6	0.68	14.9
Year	7 972.4	15.5	7 987.9	0.834	1.291	0.812	1.257	40.39	17.51	43.5	17.06	42.2

PAWTUCKET, R. I., WATER WORKS, 1910.

Jan.	1 388.8	51.0	1 439.8	1.711	2.647	1.724	2.668	4.88	3.05	62.5	3.08	63.1
Feb.	1 474.2	30.3	1 504.5	2.010	3.111	1.995	3.086	3.38	3.24	96.0	3.21	95.0
Mar.	1 544.3	1.6	1 545.9	1.902	2.943	1.851	2.864	1.82	3.40	187.0	3.30	181.3
Apr.	470.7	−13.0	457.7	0.599	0.927	0.566	0.876	1.97	1.03	52.4	0.98	49.7
May	396.8	−30.0	366.8	0.489	0.756	0.439	0.680	2.16	0.87	40.3	0.78	36.1
June	447.5	−29.9	417.6	0.570	0.881	0.517	0.799	3.24	0.98	30.2	0.89	27.5
July	106.4	−62.2	44.2	0.131	0.203	0.053	0.082	1.20	0.23	19.2	0.09	7.5
Aug.	105.3	−45.3	60.0	0.130	0.201	0.072	0.111	2.02	0.23	11.4	0.14	6.9
Sept.	130.2	−32.8	97.4	0.166	0.256	0.120	0.186	1.60	0.29	18.1	0.21	13.1
Oct.	44.0	−24.7	19.3	0.054	0.084	0.023	0.036	1.26	0.10	8.0	0.04	3.2
Nov.	68.8	35.0	103.8	0.088	0.136	0.128	0.199	4.94	0.15	3.0	0.22	4.5
Dec.	221.0	10.4	231.4	0.272	0.421	0.277	0.429	2.31	0.48	20.8	0.49	21.2
Year	6 398.0	−109.6	6 288.4	0.669	1.036	0.640	0.989	30.78	14.05	45.7	13.43	43.7

PAWTUCKET, R. I., WATER WORKS, 1911.

Jan.	452.7	27.1	479.8	0.558	0.863	0.575	0.889	3.04	1.00	32.9	1.03	33.9
Feb.	517.5	17.4	534.9	0.706	1.092	0.709	1.097	2.39	1.14	47.7	1.14	47.7
Mar.	817.8	25.1	842.9	1.007	1.559	1.009	1.562	3.63	1.80	49.6	1.80	49.6
Apr.	1 295.1	7.0	1 302.1	1.648	2.551	1.611	2.493	3.51	2.85	81.3	2.78	79.2
May	499.1	−32.3	466.8	0.615	0.951	0.559	0.865	1.98	1.10	55.6	1.00	50.5
June	328.9	−41.1	287.8	0.419	0.648	0.356	0.551	2.38	0.72	30.3	0.62	26.1
July	145.7	−29.0	116.7	0.179	0.278	0.140	0.216	3.75	0.32	8.5	0.25	6.7
Aug.	161.0	18.5	179.5	0.198	0.307	0.215	0.332	6.92	0.35	5.1	0.38	5.5
Sept.	360.8	−19.9	340.9	0.459	0.711	0.422	0.653	2.59	0.79	30.5	0.73	28.2
Oct.	416.3	−2.2	414.1	0.513	0.793	0.496	0.767	2.99	0.91	30.4	0.88	29.4
Nov.	902.5	51.4	953.9	1.149	1.777	1.180	1.826	6.20	1.98	32.3	2.04	32.9
Dec.	1 228.8	27.2	1 256.0	1.514	2.342	1.504	2.327	3.60	2.70	75.1	2.68	74.4
Year	7 126.2	49.2	7 175.4	0.746	1.154	0.730	1.129	42.98	15.66	36.5	15.33	35.7

PAWTUCKET, R. I., WATER WORKS, 1912.
Total drainage area, 26.94 sq. miles. Area of land surface, 26.21 sq. miles.

Jan.	874.6	32.2	906.8	1.076	1.665	1.086	1.680	3.49	1.92	55.0	1.94	55.6
Feb.	1 098.3	22.6	1 120.9	1.445	2.236	1.435	2.220	2.82	2.41	85.5	2.39	84.8
Mar.	2 298.2	78.7	2 376.9	2.829	4.376	2.846	4.404	7.87	5.04	64.1	5.08	64.6
Apr.	1 691.2	14.6	1 705.8	2.151	3.328	2.111	3.265	4.12	3.72	90.3	3.64	88.3
May	1 344.5	−2.8	1 341.7	1.655	2.560	1.606	2.486	4.24	2.95	69.6	2.87	67.7
June	402.3	−62.4	339.9	0.512	0.792	0.421	0.651	0.65	0.88	135.2	0.73	112.3
July	157.0	−35.9	121.1	0.193	0.299	0.145	0.224	3.16	0.34	10.8	0.26	8.2
Aug.	150.2	−24.5	125.7	0.185	0.286	0.150	0.233	3.58	0.33	9.2	0.27	7.5
Sept.	93.7	−28.9	64.8	0.119	0.185	0.080	0.124	1.85	0.21	11.4	0.14	7.6
Oct.	160.6	4.2	164.8	0.198	0.306	0.197	0.305	3.49	0.35	10.0	0.35	10.0
Nov.	255.0	14.3	269.3	0.324	0.502	0.333	0.516	3.37	0.56	16.6	0.57	16.9
Dec.	591.4	58.4	649.8	0.728	1.126	0.778	1.204	6.09	1.30	21.3	1.39	22.8
Year	9 117.0	70.5	9 187.5	0.950	1.471	0.932	1.442	44.73	20.01	44.7	19.63	43.9

HARTFORD, CONN., WATER WORKS.

Information furnished by Caleb Mills Saville, chief engineer.

The records present the combined yield of a number of small streams on the easterly slope of Talcott Mountain at West Hartford, Conn., for the period from June, 1909, to the end of 1912. These streams flow into reservoirs, which in turn discharge into Reservoir No. 1, from which the supply of the city of Hartford is taken.

Drainage area, including water surfaces		11.92 sq. miles
Area of water surfaces	0.70	
30 per cent. of 0.5 sq. miles of undrained swamps	0.15	
Total area reckoned as water surface		0.85 sq. miles
Area of land (upland) surface		11.07 sq. miles

HARTFORD, CONN., WATER WORKS, 1909.

Yield of Hartford Reservoirs. Total drainage area, 11.92 sq. miles. Area of land surface, 11.07 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area, Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	....	....	....	....	....	....	....	....	....	....	....	....
Feb.	....	....	....	....	....	....	....	....	....	....	....	....
Mar.	....	....	....	....	....	....	....	....	....	....	....	....
Apr.	....	....	....	....	....	....	....	....	....	....	....	....
May	....	....	....	....	....	....	....	....	....	....	....	....
June	117.6	−40.6	77	0.354	0.548	0.22	0.34	2.78	0.61	21.9	0.37	13
July	7.5	−56.5	−49	0.022	0.034	−0.13	−0.20	1.92	0.04	2.8	−0.24	−12
Aug.	50.6	−21.6	29	0.148	0.229	0.08	0.12	3.82	0.26	6.8	0.14	4
Sept.	48.9	−5.9	43	0.147	0.227	0.12	0.19	3.62	0.25	6.9	0.21	6
Oct.	45.1	−16.1	29	0.131	0.203	0.08	0.12	1.66	0.24	14.5	0.14	8
Nov.	56.2	0.8	57	0.169	0.262	0.16	0.25	2.33	0.29	12.4	0.28	12
Dec.	181.8	14.2	196	0.530	0.820	0.53	0.82	3.15	0.95	30.1	0.95	30
Year	507.7	−125.7	382.0	0.214	0.331	0.15	0.23	19.28	2.64	13.7	1.85	9.6
HARTFORD, CONN., WATER WORKS, 1910.												
Jan.	908.7	58.0	966.7	2.60	4.02	2.62	4.06	6.12	4.72	77.1	4.67	76
Feb.	662.6	35.8	698.4	2.11	2.27	2.09	3.24	3.81	3.44	90.3	3.37	88
Mar.	812.9	−6.8	806.1	2.36	3.65	2.18	3.38	1.22	4.23	347.0	3.99	327
Apr.	474.5	15.8	490.3	1.42	2.20	1.37	2.12	4.10	2.47	60.2	2.37	58
May	220.6	−26.4	194 2	0.64	0.99	0.52	0.80	2.57	1.15	44.8	0.94	37
June	262.9	−22.6	240.3	0.79	1.22	0.67	1.04	3.92	1.37	34.9	1.16	30
July	47.8	−47.4	0.4	0.14	0.21	0.00	0.00	2.49	0.25	10.0	0.00	0
Aug.	34.3	−39.1	−4.8	0.10	0.15	−0.01	−0.02	2.52	0.18	7.1	−0.02	−1
Sept.	33.7	−12.3	21.4	0.10	0.15	0.06	0.09	3.14	0.17	5.4	0.10	3
Oct.	19.4	−27.5	−8.1	0.06	0.09	−0.02	−0.03	0.88	0.10	11.4	−0.04	−5
Nov.	79.7	27.7	107.4	0.24	0.37	0.30	0.46	4.65	0.41	8.8	0.52	11
Dec.	132.5	1.7	134.2	0.38	0.59	0.36	0.56	1.66	0.69	41.6	0.65	39
Year	3 689.6	−43.1	3 646.5	0.91	1.40	0.84	1.30	37.08	19.18	51.7	17.83	48

HARTFORD, CONN., WATER WORKS, 1911.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	236.7	18.2	254.9	0.68	1.05	0.69	1.07	2.61	1.23	47.1	1.23	47
Feb.	227.8	14.5	242.3	0.72	1.12	0.72	1.12	2.36	1.18	50.0	1.17	50
Mar.	736.0	23.4	759.4	2.11	3.26	2.06	3.18	3.75	3.82	101.9	3.67	98
Apr.	744.7	−0.1	744.6	2.23	3.45	2.08	3.22	2.96	3.87	130.8	3.60	122
May	118.2	−38.0	80.2	0.34	0.53	0.22	0.34	1.65	0.61	37.0	0.39	24
June	111.3	−40.2	71.1	0.33	0.51	0.20	0.31	2.48	0.58	23.4	0.34	14
July	36.3	−40.2	−3.9	0.10	0.16	−0.01	−0.02	2.81	0.19	6.8	−0.02	−1
Aug.	57.4	6.8	64.2	0.16	0.26	0.17	0.27	6.06	0.30	5.0	0.31	5
Sept.	88.2	−21.2	67.0	0.26	0.40	0.19	0.29	2.24	0.46	20.5	0.32	14
Oct.	882.8	77.5	960.3	2.53	3.92	2.60	4.02	9.83	4.59	46.7	4.64	47
Nov.	596.0	25.4	621.4	1.78	2.76	1.74	2.69	4.17	3.10	74.4	3.00	72
Dec.	478.4	23.2	501.6	1.38	2.14	1.36	2.10	3.19	2.49	78.0	2.42	76
Year	4 313.8	49.3	4 363.1	1.05	1.63	1.00	1.55	44.11	22.42	50.8	21.07	48

HARTFORD, CONN., WATER WORKS, 1912.

Jan.	99.0	9.4	108.4	0.29	0.45	0.29	0.45	1.63	0.51	31.3	0.52	32
Feb.	374.0	25.2	399.2	1.16	1.80	1.16	1.79	2.89	1.95	67.5	1.93	67
Mar.	1 049.7	63.3	1 113.0	3.04	4.71	3.02	4.66	6.17	5.45	88.3	5.37	87
Apr.	534.2	15.6	549.8	1.60	2.48	1.54	2.38	4.07	2.78	68.3	2.66	65
May	745.8	9.0	754.8	2.17	3.36	2.02	3.13	5.10	3.88	76.1	3.62	71
June	57.1	−70.0	−12.9	0.17	0.26	−0.04	−0.06	0.51	0.30	58.8	−0.06	−12
July	33.7	−51.0	−17.3	0.10	0.15	−0.05	−0.07	2.12	0.18	8.5	−0.08	−4
Aug.	27.8	−30.3	−2.5	0.08	0.12	−0.01	−0.01	3.08	0.14	4.5	−0.01	−0.4
Sept.	25.2	−22.7	2.5	0.07	0.12	0.01	0.01	2.21	0.13	5.9	0.01	0.5
Oct.	44.2	−13.6	30.6	0.13	0.20	0.08	0.13	1.92	0.23	12.0	0.15	8
Nov.	97.8	18.0	115.8	0.29	0.44	0.32	0.50	4.04	0.50	12.4	0.56	14
Dec.	322.9	25.0	347.9	0.91	1.41	0.94	1.46	4.29	1.68	39.1	1.68	39
Year	3 411.4	−22.1	3 389.3	0.83	1.29	0.78	1.20	38.03	17.73	46.6	16.35	43

Full corrections are made for the water drained from or added to storage, except that no allowance is made for the storage in the ground surrounding the reservoirs. It is estimated that the total leakage from the reservoirs when they are full is about 200 000 gal. daily, and due allowance is made therefor in the computations.

The drainage area has steep slopes. The soil is of a reddish clayey nature and somewhat impervious. It is estimated that about 70 per cent. of the area is forested and uninhabited, the remainder being open farming and pasture land.

The elevation above the sea ranges from 260 to 950 ft., and averages about 460 ft.

The water consumed by the city is measured by a Venturi meter at Reservoir No. 1. The water wasted is measured by a standard weir, and the leakage is also measured by weirs.

The precipitation is measured at three well-distributed places on the drainage area, with United States Weather Bureau standard 8-in. gages. The snowfall in the rain gages is melted and measured.

NORWICH, CONN., WATER WORKS.

Fairview and Meadow Brooks.

Information furnished by C. E. Chandler, civil engineer.

The yield of the Fairview and Meadow brooks is measured at the Fairview Reservoir and the records cover the years 1910–1912.

Drainage area, including water surfaces		2.300 sq. miles
Area of water surfaces	0.125	
40 per cent. of 0.117 sq. miles of undrained swamps,	0.047	
Total area reckoned as water surfaces		0.172 sq. miles
Area of land (upland) surface		2.128 sq. miles

Full corrections are made for the water drained from or added to storage, but no allowance is made for a moderate amount of ground water storage. There is probably no percolation or leakage to materially affect the records of run-off.

NORWICH, CONN., WATER WORKS, 1910.

Yield of Fairview and Meadow brooks. Total drainage area, 2.3 sq. miles. Area of land surface, 2.128 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land surface.		Total area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. Per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	125	12	137	1.902	2.945	1.921	2.972	4.70	3.38	72	3.43	73
Feb.	127	8	135	2.170	3.364	2.096	3.242	3.64	3.43	94	3.38	93
Mar.	120	−3	117	1.870	2.898	1.640	2.538	0.84	3.24	386	2.93	349
Apr.	59	−2	57	0.950	1.473	0.826	1.277	2.47	1.60	65	1.43	58
May	51	−9	42	0.794	1.225	0.588	0.910	2.17	1.38	64	1.05	48
June	34	−10	24	0.547	0.837	0.347	0.537	2.81	0.92	33	0.60	21
July	9	−12	−3	0.140	0.217	−0.042	−0.065	2.90	0.24	8	−0.08	−3
Aug.	5	0	5	0.077	0.119	0.070	0.108	4.34	0.14	3	0.13	3
Sept.	9	−7	2	0.142	0.217	0.028	0.044	1.73	0.24	14	0.05	3
Oct.	8	−4	4	0.125	0.194	0.056	0.086	1.73	0.22	13	0.10	6
Nov.	11	3	14	0.168	0.264	0.202	0.316	3.44	0.30	9	0.35	10
Dec.	19	1	20	0.281	0.434	0.280	0.433	2.15	0.51	24	0.50	23
Year	577	−23	554	0.764	1.182	0.668	1.033	32.92	15.60	47	13.87	42

NORWICH, CONN., WATER WORKS, 1911.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	42	12	54	0.639	0.975	0.738	1.143	3.82	1.14	30	1.35	35
Feb.	53	3	56	0.890	1.380	0.839	1.298	2.20	1.43	65	1.40	64
Mar.	90	6	96	1.350	2.093	1.346	2.082	3.72	2.43	65	2.40	65
Apr.	114	0	114	1.809	2.804	1.652	2.555	3.10	3.09	100	2.85	92
May	33	−13	20	0.522	0.869	0.280	0.433	0.69	0.89	129	0.50	72
June	21	−12	9	0.333	0.516	0.130	0.201	2.00	0.57	28	0.23	12
July	1	−13	−12	0.015	0.023	−0.168	−0.260	2.05	0.03	9	−0.30	−15
Aug.	4	−4	0	0.061	0.094	0.000	0.000	4.33	0.11	3	0.00	0
Sept.	12	−6	6	0.188	0.291	0.086	0.134	2.07	0.32	15	0.15	7
Oct.	16	0	16	0.243	0.377	0.224	0.346	3.11	0.43	14	0.40	13
Nov.	57	14	71	0.896	1.390	1.028	1.591	6.73	1.54	23	1.78	26
Dec.	99	4	103	1.520	2.356	1.444	2.234	2.68	2.68	100	2.58	96
Year	542	−9	533	0.706	1.097	0.633	0.982	36.50	14.66	40	13.34	37

NORWICH, CONN., WATER WORKS, 1912.

Jan.	61	4	65	0.912	1.411	0.912	1.411	2.43	1.65	68	1.63	67
Feb.	66	3	69	1.055	1.632	1.034	1.600	2.40	1.78	74	1.73	72
Mar.	209	17	226	3.138	4.854	3.170	4.904	8.06	5.65	70	5.65	70
Apr.	148	4	152	2.318	3.586	2.200	3.403	4.33	4.00	92	3.81	88
May	193	0	193	2.925	4.525	2.707	4.188	4.49	5.22	116	4.83	108
June	22	−14	8	0.344	0.532	0.116	0.179	0.60	0.60	100	0.20	33
July	0	−3	−3	0.000	0.000	−0.042	−0.065	5.44	0.00	0	−0.08	−1.5
Aug.	8	−7	1	0.120	0.186	0.014	0.021	2.75	0.22	8	0.03	1.1
Sept.	4	−4	0	0.062	0.096	0.000	0.000	2.56	0.11	4	0.00	0
Oct.	1	−4	−3	0.015	0.023	−0.042	−0.065	1.39	0.03	2	−0.08	6
Nov.	27	3	30	0.331	0.512	0.435	0.673	3.82	0.73	19	0.75	20
Dec.	56	10	66	0.782	1.210	0.925	1.431	6.74	1.51	22	1.65	24
Year	795	9	804	1.000	1.547	0.952	1.473	45.01	21.50	48	20.12	45

The drainage area is hilly, but the hills are not steep; there is very little forested and the soil is of an average character.

The elevation above the sea ranges from 260 to 480, and averages about 300 ft.

The water is measured through a Venturi meter, but for various reasons there may be inaccuracies in the records as great as 15 per cent.

The precipitation is measured by an old-fashioned rain gage located on the roof of City Hall, three miles from the drainage area. The water is poured into a graduated glass for measurements. Twelve inches of snow are counted as one inch of rain.

WATERBURY, CONN., WATER WORKS.

Wigwam Reservoir.

Information furnished by R. A. Cairns, city engineer.

The records presented give the yield of the west branch of the Naugatuck River at the Wigwam Dam for the years 1908–1912 inclusive.

Drainage area, including water surfaces		18.00 sq. miles
Area of water surfaces	0.180	
30 per cent. of 0.023 sq. miles of drained swamps	0.007	
40 per cent. of 0.039 sq. miles of undrained swamps,	0.016	
Total area reckoned as water surfaces		0.20 sq. miles
Area of land (upland) surface		17.80 sq. miles

Full corrections are made for the water drained from or added to storage. There is very little storage in the ground surrounding the reservoirs, and no allowance is made for it. There is practically no leakage.

It is estimated that about two thirds of the drainage area is forested. The soil is generally impervious.

The elevation above the sea varies from 500 to 1 100 ft., and averages about 890 ft.

WATERBURY, CONN., WATER WORKS, 1908.

Yield of west branch of Naugatuck River. Total drainage area, 18 sq. miles. Area of land surface, 17.80 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	1 119.2	11.3	1 130.5	2.028	3.139	2.028	3.137	4.22	3.62	85.8	3.618	86
Feb.	1 182.4	16.2	1 198.6	2.291	3.549	2.297	3.553	5.71	3.82	66.9	3.832	67
Mar.	1 124.5	4.2	1 128.7	2.038	3.153	2.022	3.131	2.92	3.63	124.4	3.608	124
Apr.	559.2	−1.7	557.5	1.047	1.621	1.032	1.598	2.48	1.81	73.0	1.782	72
May	644.4	7.1	651.5	1.168	1.808	1.167	1.808	6.53	2.08	31.8	2.082	32
June	181.9	−15.0	166.9	0.341	0.528	0.309	0.478	1.22	0.59	48.4	0.534	44
July	65.6	−4.7	60.9	0.119	0.184	0.109	0.169	4.49	0.21	4.7	0.195	4
Aug.	64.4	−2.8	61.6	0.118	0.183	0.110	0.170	4.47	0.21	4.7	0.197	4
Sept.	24.0	−4.3	19.7	0.045	0.070	0.036	0.056	2.04	0.08	3.9	0.063	3
Oct.	52.0	−1.7	50.3	0.094	0.146	0.090	0.139	2.05	0.17	8.3	0.161	8
Nov.	60.5	−1.7	58.8	0.113	0.175	0.109	0.169	0.97	0.19	19.6	0.188	19
Dec.	156.6	2.4	159.0	0.284	0.440	0.285	0.441	3.31	0.51	15.4	0.508	15
Year	5 234.7	9.3	5 244.0	0.804	1.245	0.796	1.232	40.41	16.92	41.86	16.768	41

WATERBURY, CONN., WATER WORKS, 1909.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	534.3	6.1	540.4	0.969	1.500	0.969	1.501	3.84	1.73	45.0	1.727	45
Feb.	1 413.6	16.9	1 430.5	2.835	4.389	2.830	4.393	6.43	4.57	71.1	4.575	71
Mar.	1 270.3	11.1	1 281.4	2.302	3.565	2.297	3.554	4.91	4.11	83.7	4.096	83
Apr.	2 059.8	19.3	2 079.1	3.854	5.969	3.848	5.958	8.51	6.65	78.1	6.645	78
May	804.0	−4.9	799.1	1.457	2.255	1.432	2.218	3.08	2.60	84.4	2.555	83
June	158.6	−10.1	148.5	0.297	0.460	0.275	0.426	2.62	0.51	19.5	0.475	18
July	28.7	−12.5	16.2	0.052	0.081	0.029	0.045	1.99	0.09	4.5	0.052	3
Aug.	48.7	−4.5	44.2	0.088	0.136	0.079	0.122	3.88	0.16	4.1	0.141	4
Sept.	40.8	−1.0	39.8	0.076	0.118	0.074	0.115	3.72	0.13	3.5	0.127	3
Oct.	43.4	−3.3	40.1	0.079	0.122	0.072	0.111	1.34	0.14	10.5	0.128	10
Nov.	82.3	−1.0	81.3	0.154	0.238	0.151	0.234	1.57	0.27	17.2	0.260	17
Dec.	284.2	5.4	289.6	0.515	0.797	0.519	0.804	4.93	0.92	18.7	0.926	19
Year	6 768.7	21.5	6 790.2	1.042	1.614	1.033	1.599	46.82	21.88	46.7	21.707	46

WATERBURY, CONN., WATER WORKS, 1910.

Jan.	1 551.2	14.6	1 565.8	2.821	4.369	2.805	4.342	6.94	5.01	72.2	5.008	72
Feb.	958.7	9.9	968.6	1.924	2.978	1.922	2.975	4.24	3.10	73.1	3.098	73
Mar.	1 753.4	−1.7	1 751.7	3.177	4.919	3.139	4.856	1.19	5.67	476.4	5.600	471
Apr.	695.3	3.8	699.1	1.302	2.017	1.295	2.002	4.07	2.25	55.3	2.235	55
May	564.0	−2.1	561.9	1.022	1.583	1.006	1.557	3.85	1.83	47.5	1.796	47
June	674.9	−7.0	667.9	1.264	1.957	1.236	1.912	3.53	2.18	61.8	2.104	60
July	60.2	−9.6	50.6	0.109	0.169	0.091	0.141	3.09	0.19	6.2	0.162	5
Aug.	92.9	−6.3	86.6	0.168	0.260	0.155	0.240	3.59	0.30	8.4	0.277	8
Sept.	41.7	−4.2	37.5	0.078	0.121	0.070	0.108	2.52	0.14	5.6	0.120	5
Oct.	22.8	−5.2	17.6	0.041	0.063	0.032	0.050	0.64	0.07	10.9	0.056	9
Nov.	241.3	4.0	245.3	0.452	0.700	0.455	0.704	4.46	0.78	17.5	0.784	18
Dec.	272.7	1.6	274.3	0.494	0.764	0.492	0.761	2.26	0.88	38.9	0.878	39
Year	6 929.1	−2.2	6 926.9	1.067	1.652	1.055	1.634	40.38	22.40	55.5	22.118	55

WATERBURY, CONN., WATER WORKS, 1911.

Jan.	501.3	4.5	505.8	0.908	1.405	0.906	1.402	2.58	1.62	62.8	1.616	63
Feb.	372.8	5.0	377.8	0.748	1.158	0.749	1.160	2.52	1.21	48.0	1.208	48
Mar.	940.1	9.6	949.7	1.706	2.641	1.702	2.634	4.47	3.04	68.0	3.037	68
Apr.	1 013.2	−0.9	1 012.3	1.897	2.938	1.875	2.902	2.72	3.27	120.3	3.238	119
May	219.8	−12.5	207.3	0.398	0.616	0.372	0.576	0.87	0.71	81.6	0.663	76
June	152.0	−9.2	142.8	0.285	0.441	0.264	0.409	2 89	0.49	17.0	0.457	16
July	58.3	−6.1	52.2	0.106	0.164	0.094	0.146	4.16	0.19	4.6	0.167	4
Aug.	98.2	1.7	99.9	0.178	0.275	0.179	0.277	6.08	0.32	5.3	0.319	5
Sept.	229.0	−2.4	226.6	0.429	0.664	0.420	0.650	3.32	0.74	22.3	0.724	22
Oct.	1 705.3	16.0	1 721.3	3.092	4.788	3.085	4.776	8.00	5.51	68.9	5.502	69
Nov.	1 020.0	6.4	1 026.4	1.911	2.959	1.901	2.943	4.11	3.30	80.3	3.281	80
Dec.	721.6	5.0	726.6	1.307	2.023	1.303	2.018	2.97	2.33	78.4	2.322	78
Year	7 031.6	17.1	7 048.7	1.082	1.676	1.072	1.660	44.69	22.73	50.9	22.534	50.5

WATERBURY, CONN., WATER WORKS, 1912.

Jan.	319.6	3.3	322.9	0.579	0.896	0.579	0.896	1.91	1.03	53.9	1.032	54
Feb.	749.9	6.8	756.7	1.451	2.247	1.450	2.243	3.02	2.42	80.1	2.420	80
Mar.	2 093.1	18.2	2 111.3	3.798	5.875	3.785	5.859	6.95	6.77	97.4	6.750	97
Apr.	1 065.4	3.0	1 068.4	1.995	3.088	1.979	3.062	3.80	3.44	90.6	3.416	90
May	980.6	−0.9	979.7	1.778	2.752	1.755	2.717	4.21	3.17	75.2	3.131	74
June	100.7	−15.3	85.4	0.189	0.292	0.158	0.245	1.12	0.33	29.5	0.273	24
July	19.9	−11.8	8.1	0.036	0.056	0.014	0.022	2.40	0.06	2.5	0.026	1
Aug.	29.9	−7.0	22.9	0.054	0.084	0.041	0.063	2.98	0.10	3.4	0.073	2
Sept.	21.2	−5.2	16.0	0.040	0.062	0.030	0.046	1.64	0.07	4.3	0.051	3
Oct.	100.4	1.2	101.6	0.182	0.282	0.182	0.282	3.88	0.32	8.2	0.325	8
Nov.	353.6	4.7	358.3	0.662	1.025	0.664	1.027	4.50	1.14	25.3	1.145	27
Dec.	610.5	9.7	620.2	1.107	1.714	1.112	1.721	4.60	1.97	42.8	1.983	43
Year	6 444.8	6.7	6 451.5	0.990	1.532	0.979	1.515	41.01	20.82	50.8	20.625	50.3

The water wasted from the reservoir is generally measured over the spillway, for which a coefficient has been determined by tests made by building a standard weir downstream. Occasional use is made of blow-off pipes, and the discharge from these is approximated. The water drawn for consumption is measured through a Venturi meter. During the years under consideration, the amount wasted was about twice as great as the amount drawn for consumption.

The precipitation is measured by two gages, one a Friez tipping-bucket recording gage, checked by stick measurement, and the other, located a mile distant, a non-recording Friez gage with stick measurement. The snowfall is determined in accordance with United States Weather Bureau instructions.

NEW YORK WATER SUPPLY.

Croton River.

The records cover two dry periods, the first from June, 1879, to the end of 1883, and the second from 1908 to December, 1913.

During the earlier period the yield was measured at the old Croton Dam, and the results, as given in the report of John R. Freeman to Bird S. Coler, comptroller of the city of New York, dated March, 1900, were used. In obtaining these results no account was taken of the swamps upon the drainage area, which at this time had an area of about 8 sq. miles.

Drainage area, including water surfaces	338.8 sq. miles
Area of water surfaces of reservoirs, ponds, and streams	8.6 sq. miles
Area of land surface	330.2 sq. miles

Full corrections were made for the water drained from or added to storage, although the information relating to some of the smaller ponds and reservoirs was somewhat limited. No allowance was made for the storage in the ground surrounding the reservoirs.

During the interval between 1883 and 1908, the conditions were changed by the building of the new Croton Dam a few miles

downstream from the old dam, thus increasing the storage and drainage area, and by the building of other storage reservoirs upon the tributaries of the river.

The yield is now measured at the new Croton Dam, and information for the period 1908–1913 has been furnished by the Engineering Bureau of the Department of Water Supply, Gas, and Electricity. The drainage area during this later period contained about 7.5 sq. miles of swamps. The area of water surfaces was changed by the completion of the Croton Falls Reservoir on January 1, 1911, but as the reservoirs did not fill in the spring of 1911, no account was taken of the increase of water surfaces due to the construction of this reservoir until the year 1912.

The statistics with regard to land and water surfaces are as follows:

1908–1911, inclusive.

Drainage area, including water surfaces	360.4 sq. miles
Area of water surfaces of reservoirs, ponds, and streams and 40 per cent. of the area of swamps . .	20.5 sq. miles
Area of land surface	339.9 sq. miles

1912 and 1913.

Drainage area, including water surfaces	360.4 sq. miles
Area of water surfaces of reservoirs, ponds, and streams and 40 per cent. of the area of swamps .	22.4 sq. miles
Area of land surface	338.0 sq. miles

During the period 1879–1883 there were three precipitation stations to the end of 1881, and four afterward. During the period 1908–1913 the precipitation has been measured at nine places upon the drainage area.

The drainage area is very hilly and the ground generally of an impervious character. Information is not at hand as to the extent to which the area is forested, but it is probably less than haif of the whole area.

The elevation above the sea ranges from 200 to 1 290 ft., and averaged about 620 ft. in the earlier period and about 600 ft. in the later period.

NEW YORK WATER WORKS, 1879.

Yield of Croton River. Total drainage area, 338.8 sq. miles. Area of land surface, 330.2 sq. miles.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area, Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	....	....	....	....	....	....	....	....	....	....	....	....
Feb.	....	....	....	....	....	....	....	....	....	....	....	....
Mar.	....	....	....	....	....	....	....	....	....	....	....	....
Apr.	....	....	....	....	....	....	....	....	....	....	....	....
May	....	....	....	....	....	....	....	....	....	....	....	....
June	4 720	−40	4 680	0.476	0.736	0.460	0.712	5.27	0.82	15.6	0.80	15.2
July	3 984	−16	3 968	0.389	0.602	0.378	0.585	5.87	0.70	11.9	0.67	11.4
Aug.	6 728	216	6 944	0.657	1.016	0.661	1.023	6.95	1.17	16.8	1.18	17.0
Sept.	6 030	−120	5 910	0.608	0.941	0.581	0.899	3.32	1.05	31.6	1.00	30.1
Oct.	2 508	−369	2 139	0.245	0.379	0.204	0.316	0.69	0.44	63.8	0.36	52.2
Nov.	2 925	105	3 030	0.295	0.457	0.298	0.461	2.95	0.51	17.3	0.51	17.3
Dec.	8 149	438	8 587	0.795	1.230	0.818	1.266	4.44	1.42	32.0	1.46	32.9
Year	35 044	214	35 258	0.496	0.767	0.486	0.752	29.49	6.11	20.7	5.98	20.3

NEW YORK WATER WORKS, 1880

Jan.	14 046	369	14 415	1.372	2.123	1.371	2.122	3.43	2.45	71.5	2.45	71.4
Feb.	15 947	351	16 298	1.668	2.581	1.658	2.566	3.40	2.78	81.8	2.77	81.5
Mar.	15 946	329	16 275	1.557	2.409	1.550	2.398	3.90	2.78	71.3	2.76	70.8
Apr.	11 220	90	11 310	1.133	1.753	1.112	1.721	3.57	1.95	54.6	1.92	53.8
May	5 409	−511	4 898	0.529	0.819	0.466	0.721	1.04	0.94	90.3	0.83	79.8
June	2 299	−619	1 680	0.232	0.359	0.165	0.255	1.40	0.40	28.6	0.29	20.7
July	1 537	−18	1 519	0.150	0.232	0.145	0.224	5.86	0.27	4.6	0.26	4.4
Aug.	1 037	−200	837	0.101	0.156	0.080	0.124	4.16	0.18	4.3	0.14	3.4
Sept.	1 424	−254	1 170	0.144	0.223	0.115	0.178	2.42	0.25	10.3	0.20	8.3
Oct.	979	−49	930	0.096	0.149	0.089	0.138	2.83	0.17	6.0	0.16	5.7
Nov.	2 810	10	2 820	0.284	0.440	0.278	0.430	2.32	0.49	21.1	0.48	20.7
Dec.	2 071	161	2 232	0.202	0.313	0.212	0.328	2.59	0.36	13.9	0.38	14.7
Year	74 725	−341	74 384	0.619	0.958	0.600	0.928	36.92	13.02	35.3	12.64	34.2

NEW YORK WATER WORKS, 1881.

Jan.	4 068	582	4 650	0.397	0.614	0.443	0.686	4.85	0.71	14.6	0.79	16.3
Feb.	26 420	628	27 048	2.857	4.421	2.849	4.408	5.25	4.61	87.8	4.60	87.6
Mar.	35 329	724	36 053	3.451	5.340	3.435	5.315	6.54	6.15	94.0	6.12	93.6
Apr.	10 214	−254	9 960	1.030	1.593	0.980	1.516	1.27	1.78	140.1	1.69	133.1
May	7 225	−64	7 161	0.705	1.091	0.682	1.056	4.03	1.26	31.3	1.22	30.4
June	8 980	−130	8 850	0.906	1.402	0.871	1.348	4.67	1.56	33.4	1.50	32.1
July	2 756	−524	2 232	0.269	0.416	0.212	0.328	2.48	0.48	19.4	0.38	15.3
Aug.	920	−455	465	0.090	0.139	0.044	0.068	2.46	0.16	6.5	0.08	3.3
Sept.	800	−500	300	0.081	0.125	0.030	0.046	0.78	0.14	17.9	0.05	6.4
Oct.	2 480	−31	2 449	0.242	0.374	0.233	0.360	2.95	0.43	14.6	0.42	14.2
Nov.	2 525	445	2 970	0.255	0.394	0.292	0.452	5.23	0.44	8.4	0.50	9.6
Dec.	11 081	699	11 780	1.081	1.673	1.122	1.736	6.18	1.93	31.2	2.00	32.4
Year	112 798	1 120	113 918	0.936	1.448	0.915	1.416	46.69	19.65	42.1	19.35	41.4

NEW YORK WATER WORKS, 1882.

Jan.	14 665	556	15 221	1.432	2.216	1.449	2.242	4.68	2.56	54.7	2.59	55.4
Feb.	24 670	698	25 368	2.674	4.137	2.672	4.134	5.72	4.30	75.2	4.31	75.4
Mar.	27 093	342	27 435	2.648	4.097	2 610	4.038	3.99	4.72	118.2	4.66	116.8
Apr.	7 552	−232	7 320	0.763	1.180	0.720	1.114	1.42	1.32	93.0	1.24	87.4
May	11 934	218	12 152	1.167	1.806	1.157	1.790	5.92	2.08	35.1	2.06	34.8
June	9 178	−418	8 760	0.929	1.437	0.862	1.335	2.74	1.60	58.4	1.49	54.4
July	3 185	−426	2 759	0.311	0.481	0.263	0.407	3.13	0.55	17.6	0.47	15.0
Aug.	939	−350	589	0.092	0.142	0.056	0.087	3.16	0.16	5.1	0.10	3.2
Sept.	18 139	1 571	19 710	1.830	2.831	1.940	3.002	14.63	3.16	21.6	3.35	22.9
Oct.	11 949	−45	11 904	1.168	1.807	1.132	1.752	2.86	2.08	72.8	2.02	70.6
Nov.	5 045	−95	4 950	0.509	0.788	0.487	0.754	1.61	0.88	54.6	0.84	52.2
Dec.	6 642	147	6 789	0.648	1.003	0.646	1.000	2.49	1.16	46.6	1.15	46.2
Year	140 991	1 966	142 957	1.169	1.809	1.158	1.792	52.35	24.57	46.9	24.28	46.4

NEW YORK WATER WORKS, 1883.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area. Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	5 556	365	5 921	0.543	0.840	0.564	0.873	3.40	0.97	28.5	1.01	29.7
Feb.	17 609	647	18 256	1.908	2.952	1.924	2.977	5.38	3.07	57.1	3.10	57.6
Mar.	15 457	12	15 469	1.510	2.336	1.470	2.274	1.78	2.69	151.1	2.63	147.7
Apr.	14 303	67	14 370	1.445	2.236	1.412	2.185	3.42	2.49	72.8	2.44	71.4
May	7 290	−284	7 006	0.712	1.102	0.667	1.032	2.56	1.27	49.6	1.19	46.5
June	3 602	−152	3 450	0.363	0.562	0.340	0.526	4.52	0.63	13.9	0.59	13.1
July	2 209	−163	2 046	0.216	0.334	0.195	0.302	4.89	0.38	7.8	0.35	7.2
Aug.	1 288	−420	868	0.126	0.195	0.083	0.128	2.69	0.22	8.2	0.15	5.6
Sept.	526	−226	300	0.053	0.082	0.030	0.046	2.61	0.09	3.4	0.05	1.9
Oct.	2 423	460	2 883	0.237	0.367	0.274	0.424	6.24	0.42	6.7	0.49	7.9
Nov.	4 453	−103	4 350	0.450	0.696	0.428	0.662	1.56	0.78	50.0	0.74	47.4
Dec.	3 245	320	3 565	0.317	0.491	0.340	0.526	3.65	0.57	15.6	0.60	16.4
Year	77 961	523	78 484	0.647	1.001	0.635	0.982	42.70	13.58	31.8	13.34	31.2

NEW YORK WATER WORKS, 1908.

Total drainage area, 360.4 sq. miles. Area of land surace, 339.9 sq. miles.

Jan.	22 099	1 133	23 232	2.098	3.245	2.077	3.211	4.14	3.75	90.6	3.71	89.6
Feb.	23 896	1 743	25 639	2.426	3.751	2.453	3.794	5.94	4.05	68.3	4.09	68.9
Mar.	27 008	737	27 745	2.565	3.968	2.483	3.841	3.77	4.57	121.2	4.43	117.5
Apr.	13 091	100	13 191	1.284	1.986	1.220	1.888	3.25	2.21	68.1	2.11	64.9
May	16 119	723	16 842	1.530	2.366	1.507	2.331	6.49	2.73	42.1	2.69	41.4
June	8 736	−1 215	7 521	0.857	1.326	0.695	1.075	2.11	1.48	70.2	1.20	56.8
July	2 626	−1 206	1 420	0.249	0.385	0.127	0.196	2.51	0.45	17.9	0.23	9.2
Aug.	2 959	398	3 357	0.281	0.435	0.301	0.466	6.67	0.50	7.5	0.53	7.9
Sept.	1 523	−1 001	522	0.149	0.230	0.048	0.074	1.07	0.26	24.3	0.08	7.5
Oct.	1 250	−389	861	0.119	0.184	0.077	0.119	1.91	0.21	11.0	0.14	7.3
Nov.	1 436	−365	1 071	0.141	0.218	0.099	0.153	1.01	0.24	23.8	0.17	16.8
Dec.	2 766	520	3 286	0.263	0.407	0.294	0.455	3.38	0.47	13.9	0.52	15.4
Year	123 509	1 178	124 687	0.994	1.538	0.946	1.453	42.25	20.92	49.5	19.90	47.1

NEW YORK WATER WORKS, 1909.

Jan.	8 140	958	9 098	0.773	1.195	0.814	1.259	4.49	1.38	30.8	1.46	32.5
Feb.	22 022	1 532	23 554	2.314	3.580	2.334	3.611	6.33	3.73	59.0	3.76	59.4
Mar.	22 291	975	23 266	2.116	3.272	2.082	3.221	4.73	3.78	80.0	3.71	78.4
Apr.	27 486	1 545	29 031	2.695	4.170	2.688	4.158	7.44	4.65	62.5	4.64	62.4
May	17 902	−787	17 115	1.702	2.632	1.532	2.370	2.24	3.03	135.2	2.73	121.8
June	4 535	−839	3 696	0.445	0.689	0.342	0.529	3.16	0.77	24.4	0.59	18.7
July	1 752	−1 110	642	0.166	0.257	0.057	0.088	2.77	0.30	10.8	0.10	3.6
Aug.	3 569	275	3 844	0.339	0.524	0.344	0.532	6.32	0.60	9.5	0.61	9.7
Sept.	1 851	39	1 890	0.182	0.282	0.175	0.271	4.24	0.31	7.3	0.30	7.1
Oct.	2 221	−588	1 633	0.211	0.326	0.146	0.226	1.25	0.38	30.4	0.26	20.8
Nov.	2 358	252	2 610	0.231	0.357	0.243	0.376	3.11	0.40	12.9	0.42	13.5
Dec.	7 886	869	8 755	0.749	1.159	0.784	1.213	4.56	1.33	29.2	1.40	30.7
Year	122 013	3 121	125 134	0.984	1.522	0.951	1.471	50.64	20.66	40.8	19.98	39.5

NEW YORK WATER WORKS, 1910.

Jan.	25 436	1 980	27 416	2.415	3.735	2.454	3.795	7.47	4.31	57.8	4.38	58.6
Feb.	17 474	1 390	18 864	1.835	2.839	1.868	2.890	5.24	2.96	56.6	3.02	57.6
Mar.	30 681	−341	30 340	2.912	4.505	2.721	4.210	0.72	5.20	723.0	4.85	672.4
Apr.	12 435	744	13 179	1.219	1.885	1.219	1.885	5.06	2.11	41.6	2.10	41.3
May	12 430	−228	12 202	1.180	1.825	1.092	1.690	3.82	2.10	55.0	1.95	51.0
June	8 632	−448	8 184	0.847	1.310	0.756	1.169	4.28	1.46	34.1	1.31	30.6
July	2 584	−1 307	1 277	0.245	0.379	0.114	0.176	2.26	0.44	19.5	0.20	8.8
Aug.	2 234	−836	1 398	0.212	0.328	0.125	0.193	3.06	0.38	12.4	0.22	7.2
Sept.	1 423	−667	756	0.140	0.217	0.070	0.108	2.10	0.24	11.4	0.12	5.7
Oct.	432	−634	−202	0.041	0.063	−0.018	−0.028	1.13	0.07	6.2	−0.03	−2.7
Nov.	2 791	764	3 555	0.274	0.424	0.329	0.509	4.84	0.47	9.7	0.57	11.8
Dec.	3 088	313	3 401	0.293	0.453	0.304	0.470	2.62	0.52	19.8	0.54	20.6
Year	119 640	730	120 370	0.964	1.492	0.914	1.414	42.60	20.26	47.6	19.23	45.1

NEW YORK WATER WORKS, 1911.

Month.	Yield of Drainage Area in Million Gallons.			Yield per Sq. Mile of Land Surface.		Yield per Sq. Mile of Total Area.		Precipitation on Drainage Area, Inches.	Precipitation Collected.			
									Land Surface.		Total Area.	
	Land Surface.	Water Surface.	Total Area.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.	Inches.	Per Cent.
Jan.	7 810	600	8 410	0.742	1.148	0.753	1.165	3.17	1.32	41.6	1.34	42.3
Feb.	8 051	514	8 565	0.846	1.309	0.849	1.314	2.96	1.36	46.0	1.36	46.0
Mar.	14 302	680	14 982	1.358	2.101	1.341	2.074	4.16	2.42	58.1	2.39	57.4
Apr.	19 659	183	19 842	1.929	2.984	1.835	2.839	3.59	3.33	92.8	3.17	88.3
May	6 822	−532	6 290	0.648	1.002	0.563	0.871	2.71	1.15	42.5	1.00	36.9
June	5 016	−678	4 338	0.492	0.761	0.401	0.620	3.26	0.85	26.1	0.69	21.1
July	1 749	−952	797	0.166	0.257	0.071	0.110	2.64	0.30	11.4	0.13	4.9
Aug.	1 914	792	2 706	0.182	0.281	0.242	0.374	8.44	0.32	3.8	0.43	5.1
Sept.	6 128	−353	5 775	0.602	0.932	0.534	0.826	2.76	1.04	37.7	0.92	33.4
Oct.	18 196	974	19 170	1.727	2.672	1.715	2.652	6.75	3.08	45.6	3.06	45.3
Nov.	17 210	619	17 829	1.689	2.612	1.649	2.550	4.33	2.92	67.5	2.84	65.6
Dec.	15 672	563	16 235	1.488	2.302	1.453	2.248	3.29	2.66	81.0	2.59	78.7
Year	122 529	2 410	124 930	0.988	1.528	0.950	1.470	48.06	20.75	43.2	19.92	41.4

NEW YORK WATER WORKS, 1912.

Total drainage area, 360.4 sq. miles. Area of land surface, 338.0 sq. miles.

Jan.	8 647	343	8 990	0.825	1.276	0.80	1.24	2.10	1.47	70.0	1.44	68.6
Feb.	12 756	468	13 224	1.301	2.013	1.27	1.96	2.57	2.17	84.0	2.11	82.1
Mar.	35 635	2 061	37 696	3.401	5.262	3.37	5.22	7.57	6.07	80.2	6.02	79.5
Apr.	23 472	378	23 850	2.315	3.582	2.20	3.41	3.95	4.00	101.3	3.81	96.5
May	26 489	140	26 629	2.528	3.911	2.38	3.69	4.82	4.51	93.6	4.25	88.2
June	7 497	−1 617	5 880	0.739	1.143	0.54	0.84	1.35	1.28	89.8	0.94	69.6
July	1 831	−1 180	651	0.175	0.271	0.06	0.09	2.85	0.31	10.9	0.10	3.5
Aug.	1 929	−441	1 488	0.184	0.285	0.14	0.21	4.28	0.33	7.7	0.24	5.6
Sept.	1 698	−168	1 530	0.167	0.258	0.14	0.22	3.63	0.29	8.0	0.24	6.6
Oct.	2 931	262	3 193	0.280	0.433	0.28	0.44	3.94	0.50	12.7	0.51	12.9
Nov.	8 583	537	9 120	0.846	1.309	0.85	1.31	3.91	1.46	37.3	1.46	37.3
Dec.	10 037	1 030	11 067	0.958	1.482	0.99	1.53	4.63	1.71	36.9	1.77	38.2
Year	141 505	1 813	143 318	1.144	1.770	1.09	1.68	45.60	24.10	52.8	22.89	50.2

NEW YORK WATER WORKS, 1913.

Jan.	24 492	1 021	25 513	2.338	3.617	2.28	3.53	3.84	4.17	108.6	4.07	106.0
Feb.	9 191	609	9 800	0.971	1.502	0.98	1.50	2.68	1.56	58.2	1.57	58.6
Mar.	34 030	1 713	35 743	3.248	5.025	3.20	4.95	6.18	5.79	93.7	5.71	92.4
Apr.	34 425	945	35 370	3.395	5.253	3.27	5.06	5.42	5.86	108.2	5.64	104.1
May	15 103	−378	14 725	1.441	2.230	1.32	2.04	3.49	2.57	73.6	2.35	67.4
June	4 856	−1 736	3 120	0.479	0.741	0.28	0.44	1.04	0.82	78.9	0.50	48.1
July	1 180	−1 304	−124	0.113	0.175	−0.01	−0.02	2.49	0.20	8.0	−0.02	−0.8
Aug.	1 586	−408	1 178	0.151	0.234	0.10	0.16	4.36	0.27	6.2	0.19	4.4
Sept.	1 909	71	1 980	0.188	0.291	0.18	0.28	4.33	0.32	7.4	0.32	7.4
Oct.	16 037	2 222	18 259	1.531	2.369	1.64	2.53	9.65	2.73	28.3	2.92	30.3
Nov.	16 284	276	16 560	1.606	2.485	1.53	2.37	3.02	2.77	91.7	2.64	87.4
Dec.	12 070	485	12 555	1.152	1.782	1.12	1.74	2.82	2.05	72.7	2.01	71.3
Year	171 163	3 516	174 679	1.387	2.146	1.33	2.048	49.32	29.11	59.0	27.90	56.6

NEW YORK WATER SUPPLY.

Esopus Creek.

Information furnished by J. Waldo Smith, chief engineer, Board of Water Supply.

The yield was measured at a weir built a short distance below the site of the Ashokan Dam.

The records cover the years 1908–1913.

Drainage area, which contains practically no water surfaces, 239 sq. miles.

The total area of swamps is about 5 sq. miles. These have been neglected in making the computations.

The drainage area includes a large section of the Catskill Mountains, with the steep slopes largely wooded, mostly with second growth timber. The soil is glacial drift, largely impervious and clayey.

The elevation above the sea ranges from 590 to 4 200 ft. and averages about 1 700 ft.

The discharge is measured at a masonry weir of ogee section specially constructed for this purpose. The weir should give accurate results when there is no ice. The winters at this place are very severe and the slush ice which forms in a rapidly flowing stream under such conditions and the anchor ice affect the accu-

NEW YORK WATER WORKS, 1908.

Yield of Esopus Creek. Total drainage area (all land surface), 239 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.
January	12 874	1.73	2.68	3.49	3.101	89
February	15 057	2.17	3.36	6.40	3.625	57
March	22 858	3.08	4.77	2.93	5.501	188
April	18 629	2.60	4.02	2.98	4.486	151
May	31 425	4.24	6.56	9.23	7.560	82
June	4 699	0.65	1.01	2.29	1.138	50
July	2 724	0.37	0.57	6.32	0.657	10
August	1 129	0.15	0.23	2.04	0.271	13
September	702	0.10	0.15	2.46	0.169	7
October	3 534	0.48	0 74	4.21	0.852	20
November	3 700	0.52	0.80	0.57	0.892	156
December	4 058	0.55	0.85	2.58	0.977	38
The Year	121 389	1.43	2.21	45.50	29.229	64

NEW YORK WATER WORKS, 1909.

January	16 248	2.19	3.39	4.82	3.922	81
February	27 844	4.16	6.44	6.97	6.703	96
March	16 431	2.22	3.43	4.35	3.955	91
April	24 799	3.46	5.35	5.20	5.970	115
May	16 781	2.27	3.51	4.48	4.040	90
June	7 527	1.05	1.62	4.38	1.812	41
July	1 548	0.21	0.33	2.06	0.374	18
August	2 124	0.28	0.44	4.83	0.511	11
September	1 111	0.16	0.24	4.17	0.267	6
October	1 119	0.15	0.23	1.40	0.271	19
November	818	0.12	0.18	1.98	0.199	10
December	3 167	0.43	0.66	4.63	0.760	18
The Year	119 517	1.39	2.15	49.27	28.784	58

NEW YORK WATER WORKS, 1910.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.
January	21 582	2.91	4.50	7.61	5.201	68
February	10 968	1.64	2.54	4.37	2.639	60
March	34 150	4.60	7.12	0.93	8.222	884
April	37 974	5.30	8.19	10.18	9.141	90
May	9 207	1.24	1.92	2.95	2.217	75
June	7 898	1.10	1.70	4.59	1.902	41
July	1 847	0.25	0.38	2.02	0.443	22
August	1 291	0.17	0.27	3.93	0.307	8
September	1 969	0.27	0.42	5.21	0.475	9
October	972	0.13	0.20	1.02	0.235	23
November	2 828	0.39	0.61	3.70	0.681	18
December	4 210	0.57	0.88	2.30	1.017	44
The Year	134 896	1.55	2.40	48.81	32.480	66

NEW YORK WATER WORKS, 1911.

January	11 598	1.56	2.42	2.60	2.802	108
February	6 315	0.94	1.46	1.94	1.527	78
March	10 985	1.48	2.29	3.90	2.655	68
April	19 389	2.70	4.18	2.37	4.671	197
May	6 709	0.91	1.41	1.06	1.616	152
June	9 776	1.36	2.11	5.94	2.355	40
July	2 611	0.35	0.54	3.19	0.629	20
August	1 763	0.24	0.37	4.83	0.421	9
September	3 080	0.43	0.67	4.25	0.740	17
October	18 205	2.46	3.80	7.50	4.392	59
November	11 195	1.56	2.42	3.50	2.701	77
December	10 559	1.43	2.21	2.91	2.552	88
The Year	112 185	1.29	1.99	43.99	27.061	62

NEW YORK WATER WORKS, 1912.

January	6 548	0.89	1.37	2.38	1.577	66
February	8 615	1.24	1.92	2.96	2.071	70
March	29 939	4.04	6.25	5.96	7.208	121
April	33 687	4.70	7.27	5.76	8.107	141
May	16 403	2.22	3.43	4.36	3.948	91
June	3 651	0.51	0.79	1.72	0.876	51
July	1 546	0.21	0.32	3.25	0.370	11
August	4 640	0.63	0.97	7.47	1.116	15
September	2 999	0.42	0.65	3.44	0.718	21
October	7 052	0.96	1.47	4.84	1.698	35
November	11 172	1.56	2.41	4.08	2.691	66
December	14 128	1.91	2.95	4.70	3.415	73
The Year	140 380	1.61	2.49	50.92	33.795	66

NEW YORK WATER WORKS, 1913.

January	23 130	3.12	4.83	4.26	5.569	130.7
February	5 004	0.75	1.16	2.28	1.202	52.7
March	29 760	4.02	6.21	7.70	7.161	93.0
April	14 888	2.08	3.21	3.81	3.583	94.0
May	9 251	1.25	1.93	3.74	2.229	59.6
June	4 476	0.63	0.97	1.01	1.077	106.6
July	824	0.11	0.17	1.90	0.203	10.7
August	876	0.12	0.18	4.86	0.215	4.4
September	1 843	0.26	0.40	4.02	0.445	11.1
October	14 048	1.89	2.93	6.76	3.383	50.0
November	27 164	3.79	5.86	5.60	6.538	116.8
December	9 985	1.35	2.08	2.93	2.405	82.1
The Year	141 249	1.61	2.49	48.87	34.010	69.6

racy of the measurements in the winter season. More accurate measurements can be obtained in the future when the reservoir is in use, as most of the water will be measured through the aqueduct.

Many well-distributed rain gages are used to measure the precipitation on the Catskill drainage areas. Badger weighing gages are used at Sundown and Venetia, a Friez automatic type bucket gage at Brown's Station, and the remainder are 8-in. United States Weather Bureau standard gages, some of them located at the highest elevations at which observers could be obtained. The snowfall is measured by reducing snow collected in gage to water equivalent and measuring. The average depth of snow is also measured on the ground. There are no gages on the tops of the highest mountains, which are inaccessible during a large part of the year. As a result, although the rainfall recorded is very high, especially at the highest stations, showing to a marked degree that the precipitation increases with the elevation, it is probable that the average rainfall upon the drainage area is higher than that recorded.

NEW YORK WATER SUPPLY.

Rondout Creek.

Information furnished by J. Waldo Smith, chief engineer, Board of Water Supply.

The yield was measured at Honk Falls to and including April, 1910, and at Lackawack from May, 1910, until the end of the period.

The records cover the years 1908–1911.

Drainage area, which contains practically no water surfaces, to April, 1910, inclusive	102 sq. miles
After April, 1910	100 sq. miles

There are no swamps.

The drainage area includes a section of the Catskill Mountains, with the steep slopes largely wooded with second growth timber. The soil is glacial drift, largely impervious and clayey.

The elevation above the sea ranges from about 700 ft. to 4 200 ft. and averages about 1 600 ft.

NEW YORK WATER WORKS, 1908.

Yield of Rondout Creek. Total drainage area (all land surface), 102 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.	Inches.	Inches.	Per Cent.
January	5 206	1.65	2.55	3.12	2.937	94.1
February	6 037	2.04	3.15	6.24	3.405	54.6
March	10 345	3.27	5.06	3.53	5.836	165.3
April	9 075	2.97	4.59	4.02	5.119	127.3
May	9 197	2.91	4.50	7.64	5.188	67.9
June	1 620	0.53	0.82	1.75	0.914	52.2
July	785	0.25	0.39	5.08	0.443	8.7
August	597	0.19	0.29	2.59	0.337	13.0
September	275	0.09	0.14	2.64	0.155	5.9
October	612	0.19	0.29	3.74	0.345	9.2
November	738	0.24	0.37	0.72	0.416	57.8
December	1 437	0.45	0.70	3.09	0.811	26.2
The Year	45 924	1.23	1.902	44.16	25.906	58.7

NEW YORK WATER WORKS, 1909.

January	7 669	2.43	3.76	4.82	4.327	89.8
February	12 309	4.31	6.67	6.61	6.944	105.1
March	6 698	2.12	3.28	3.99	3.778	94.7
April	7 219	2.36	3.65	4.71	4.072	86.5
May	6 943	2.20	3.40	3.36	3.917	116.6
June	2 713	0.86	1.33	4.39	1.530	34.9
July	932	0.29	0.45	2.07	0.526	25.4
August	525	0.17	0.26	4.46	0.296	6.6
September	516	0.17	0.26	3.54	0.291	8.2
October	536	0.17	0.26	1.25	0.302	24.2
November	548	0.18	0.28	1.86	0.309	16.6
December	1 154	0.36	0.56	4.47	0.651	14.6
The Year	47 762	1.28	1.98	45.53	26.943	59.2

NEW YORK WATER WORKS, 1910.

Total drainage area (all land surface), January to April, 102 sq. miles; May to December, 100 sq. miles.

January	7 081	2.24	3.47	7.07	3.994	56.5
February	4 666	1.63	2.52	4.53	2.632	58.1
March	14 528	4.59	7.10	1.03	8.195	795.6
April	12 078	3.94	6.09	8.30	6.813	82.1
May	4 929	1.59	2.46	3.60	2.836	78.8
June	2 751	0.92	1.42	4.22	1.583	37.5
July	778	0.25	0.39	2.34	0.448	19.1
August	755	0.24	0.37	4.08	0.434	10.6
September	1 350	0.45	0.70	5.25	0.777	14.8
October	691	0.22	0.34	1.18	0.398	33.7
November	1 758	0.59	0.91	3.36	1.012	30.1
December	3 083	0.99	1.53	2.25	1.774	78.8
The Year	54 448	1.47	2.27	47.21	30.896	65.4

NEW YORK WATER WORKS, 1911.

Total drainage area (all land surface), 100 sq. miles.

January	5 019	1.62	2.51	3.44	2.888	83.9
February	3 811	1.36	2.10	1.99	2.193	110.2
March	6 072	1.96	3.03	4.42	3.494	79.0
April	9 390	3.13	4.84	3.11	5.403	173.7
May	2 555	0.82	1.27	1.16	1.470	126.7
June	3 954	1.32	2.04	6.57	2.275	34.6
July	1 017	0.33	0.51	3.27	0.585	17.9
August	792	0.26	0.40	5.14	0.456	8.9
September	1 540	0.51	0.79	4.17	0.886	21.2
October	7 765	2.50	3.87	7.10	4.468	62.9
November	5 356	1.79	2.77	3.43	3.082	89.9
December	5 471	1.77	2.74	3.08	3.148	102.2
The Year	52 742	1.44	2.23	46.88	30.348	64.8

The discharge is based upon the height of the water in the stream, which is recorded continuously by a Friez automatic gage; the discharge curve is based upon measurements made with a small Price current meter. It is stated that the accuracy is within 10 per cent., but in the winter in this extremely cold location the results are probably less accurate than when there is no ice.

For information regarding the precipitation, see the Esopus description.

NEW YORK WATER SUPPLY.

Schoharie Creek.

Information furnished by J. Waldo Smith, chief engineer, Board of Water Supply.

The yield was measured at Prattsville.

The records cover the years 1908–1911.

Drainage area, which contains practically no water surfaces . . . . . 236 sq. miles

There are no swamps.

The drainage area includes a large section of the Catskill Mountains, with the steep slopes heavily forested with second growth timber. The soil is glacial drift, largely impervious and clayey.

The elevation above the sea ranges from 1 130 to 4 025 ft., and averages about 2 000 ft.

Although the Schoharie Creek drainage area has an average elevation somewhat higher than those of the Esopus and Rondout creeks, it is situated beyond a high range of mountains, and slopes towards the west, so that it does not have as high a rainfall as the Esopus and Rondout drainage areas, which slope towards the south and east.

The discharge is based upon the height of the water in the stream, which is recorded morning and evening by an observer. The discharge curve is based upon measurements made with a small Price current meter. It is stated that the accuracy is within 10 per cent., but in the winter in this extremely cold location the results are probably less accurate than when there is no ice.

For information regarding the precipitation, see the Esopus description.

NEW YORK WATER WORKS, 1908.

Yield of Schoharie Creek. Total drainage area (all land surface), 236 sq. miles.

Month.	Yield of Drainage Area.	Yield per Square Mile.		Precipitation on Drainage Area. Inches.	Precipitation Collected.	
	Mil. Gal.	Mil. Gal. per Day.	Cu. Ft. per Sec.		Inches.	Per Cent.
January	8 596	1.18	1.82	2.93	2.096	71.5
February	14 299	2.09	3.23	5.51	3.486	63.3
March	19 878	2.72	4.20	2.31	4.846	209.8
April	13 956	1.97	3.05	2.68	3.402	126.9
May	19 182	2.62	4.05	7.53	4.677	62.1
June	2 818	0.40	0.62	2.22	0.687	30.9
July	1 515	0.21	0.32	4.36	0.369	8.5
August	667	0.09	0.14	2.32	0.163	7.0
September	337	0.05	0.07	2.82	0.082	2.9
October	2 587	0.35	0.54	4.31	0.631	14.6
November	1 937	0.27	0.42	0.44	0.472	107.3
December	3 895	0.53	0.82	2.01	0.950	47.3
The Year	89 667	1.04	1.61	39.44	21.861	55.4

NEW YORK WATER WORKS, 1909.

January	12 588	1.72	2.66	4.12	3.069	74.5
February	22 077	3.34	5.16	4.82	5.382	111.7
March	15 446	2.11	3.26	3.38	3.766	111.4
April	20 264	2.86	4.42	4.47	4.940	110.5
May	13 495	1.84	2.84	4.24	3.290	77.6
June	5 650	0.80	1.24	4.19	1.377	32.9
July	1 016	0.14	0.22	1.53	0.248	16.2
August	742	0.10	0.15	3.23	0.181	5.6
September	533	0.08	0.12	3.17	0.130	4.1
October	606	0.08	0.12	1.35	0.148	11.0
November	532	0.08	0.12	1.85	0.130	7.0
December	1 819	0.25	0.39	4.14	0.443	10.7
The Year	94 768	1.10	1.70	40.49	23.104	57.1

NEW YORK WATER WORKS, 1910.

January	15 928	2.18	3.37	6.67	3.883	58.2
February	14 509	2.20	3.40	3.42	3.537	103.4
March	26 285	3.59	5.55	0.62	6.408	1 033.5
April	27 037	3.82	5.91	7.76	6.592	84.9
May	7 544	1.03	1.59	3.07	1.839	59.9
June	9 671	1.37	2.12	5.03	2.358	46.9
July	1 599	0.22	0.34	1.54	0.390	25.3
August	988	0.14	0.22	2.23	0.241	10.8
September	1 089	0.15	0.23	4.22	0.266	6.3
October	1 052	0.14	0.22	0.80	0.256	32.0
November	6 032	0.85	1.32	4.94	1.471	29.8
December	6 737	0.92	1.42	1.45	1.642	113.2
The Year	118 471	1.38	2.13	41.75	28.883	69.2

NEW YORK WATER WORKS, 1911.

January	13 014	1.78	2.75	1.85	3.173	171.5
February	3 694	0.56	0.87	1.13	0.900	79.6
March	11 586	1.58	2.44	2.13	2.825	132.6
April	20 608	2.91	4.50	1.43	5.024	351.3
May	5 724	0.78	1.21	1.43	1.396	97.6
June	9 317	1.32	2.04	6.09	2.271	37.3
July	824	0.11	0.17	2.06	0.201	9.8
August	681	0.09	0.14	4.16	0.166	4.0
September	2 749	0.39	0.60	3.21	0.670	20.9
October	12 305	1.68	2.60	4.68	3.000	64.1
November	7 070	0.99	1.53	1.99	1.724	86.6
December	12 110	1.66	2.57	1.79	2.952	164.9
The Year	99 682	1.16	1.79	31.95	24.302	76.1

Appendix No. 2.

EXPLANATION OF METHODS EMPLOYED IN COMPUTING CAPACITY TABLES Nos. 11 to 23.

The methods employed can be illustrated best by taking a specific case.

Let it be assumed that Capacity Table 15, page 439, relating to the Wachusett Reservoir, is to be computed to obtain the storage capacity in million gallons per square mile, with various percentages of water surface required to supply the different daily quantities of water given in the first column of the table.

The starting point for computing the second column in the table, which is headed 0 per cent., is a table giving the average yield in gallons per day per square mile of land surface of the drainage area for one, two, or more consecutive months, up to the full number of months contained in the record. Table 3, page 411, is a part of such a table. A reference to it shows that in the driest month the yield was 158 000 gal. daily per sq. mile, so that in a computation dealing only with whole months no storage would be required for a constant draft of this quantity, or less. Hence, there is a 0 in the second column opposite the figures 50 000, 100 000, and 150 000.

When the draft is 200 000 gal. daily, it may be seen by the inspection of Table 3 that the amount of storage required should be based upon the yield for the driest month. The computation is as follows:

	Gallons.
Daily draft	200 000
Daily yield	158 000
Daily deficit	42 000
Deficit for the month	42 000×31 = 1.3 mil. gal.

This is the amount of storage which would theoretically be required to supply 200 000 gal. daily from each square mile of drainage area when there are no water surfaces.

In the case of 250 000 gal. daily, it is not clear from inspection

only whether the reservoir would be depleted to the greatest extent by one, two, or three months' draft, and three separate computations may be made, as follows:

250 000
158 000

92 000×31 = 2.9 mil. gal. storage on basis of driest month.

250 000
190 000

60 000×61 = 3.7 mil. gal. storage on basis of driest two months.

250 000
205 000

45 000×92 = 4.1 mil. gal. storage on basis of driest three months.

These computations show that the greatest amount of required storage is determined on the basis of three months.

For 300 000 gal. daily, the period which gives the maximum storage is again three months.

For 350 000 gal. daily, the period is found to be five months, while for from 400 000 to 650 000 gal. daily the period giving the maximum required storage is six months.

Special attention is called to this case, where the critical period — that is, the one requiring the most storage — is the same for many different daily drafts. In such cases the additional amount of storage required for each increase of 50 000 gal. in the daily draft is constant.

Thus, the storage required to supply from 400 000 to 650 000 gal. daily per sq. mile is as follows:

400 000 — 274 000 = 126 000×184 = 23.2 mil. gal.
450 000 — 274 000 = 176 000×184 = 32.4 mil. gal.
500 000 — 274 000 = 226 000×184 = 41.6 mil. gal.
550 000 — 274 000 = 276 000×184 = 50.8 mil. gal.
600 000 — 274 000 = 326 000×184 = 60.0 mil. gal.
650 000 — 274 000 = 376 000×184 = 69.2 mil. gal.

It will be noted that for each additional 50 000 gal. daily of draft there is required 9.2 mil. gal. of storage.

When the results of the table are plotted, all portions of the diagram depending upon a given critical period are represented by straight lines. Such uniform increments in the table and straight lines upon the diagram do not represent the general law relating to the required amount of storage, which is that with an increasing draft there is still a greater increase in the required amount of storage.

The diagrams, to cover the general law, should not be made up of straight lines, but should be smooth curves. It has not been thought best, however, to try to make the diagrams for each drainage area represent the general law, but rather to make them so that they will show just the amount of storage required, should there be a recurrence of the conditions which actually existed upon the given drainage area.

A reference to Table 3 shows that the minumum yield per square mile of the land surface of the Wachusett drainage area for twelve months was 582 000 gal. daily. Hence, with any smaller draft than 582 000 gal. daily the assumed reservoir would fill each year, and up to that limit the computations of the required amount of storage are based upon the records of a part of a year. When the daily draft from the reservoir exceeds 582 000, however, the critical period upon which the storage is based may be either less or more than twelve months.

The following computations were made to determine the storage required for a draft of 700 000 gal. daily:

700 000
274 000

426 000×184 = 78.4 mil. gal. storage on basis of driest six months.

700 000
376 000

324 000×245 = 79.4 mil. gal. storage on basis of driest eight months.

700 000
532 000

168 000×488 = 82.0 mil. gal. storage on basis of driest sixteen months.

These computations show that with the draft stated the reservoir would be drawn slightly lower in sixteen months than at the end

of six or eight months. Hence, the required storage is the 82.0 million gal., based upon a critical period of sixteen months.

The remainder of this column was computed in the same manner. The critical period in the case of the highest quantity extends from June 1, 1908, to the end of January, 1914, and if the records for another year were available it might be found that a greater amount of storage than that given in the table would be required.

In order to determine the figures in the remaining columns, that is, the required storage when there are 5, 10, and 15 per cent. of water surfaces, the computations are more extended. The critical period which served as a basis for the figures in the second column often is the same that would serve as a basis for the figures in the other columns, but this rule has many exceptions, as a large evaporation from water surfaces may offset a difference in the rate of run-off from the land surfaces.

The first step in ascertaining the required storage for the three columns above mentioned is to ascertain the net yield of the water surfaces for such single months and periods of consecutive months as seem likely to furnish a minimum yield from land and water surfaces combined.

The yield of a water surface is the difference between the evaporation from and rainfall upon it. The difference gives the net yield per month or months in inches, and this can be converted into the yield in gallons per day per square mile of water surface. The following are examples:

The minimum yield from the land surface of the Wachusett drainage area occurred in October, 1910. The evaporation for October, as given on page 409, is 3.16 in., and the rainfall in October, 1910, was 1.40 in. The difference between the evaporation and rainfall, or the net loss for the month, is 1.76 in., which equals 986 000 gal. per day per sq. mile of water surface.

The yield from the land surface in July, 1913, was low, although greater than in October, 1910. The evaporation for July is 5.98 in. and the rainfall in July, 1913, was 2.37 in. The difference between the evaporation and rainfall is 3.61 in., equal to a net loss of 2 025 000 gal. per day per sq. mile of water surface.

Although the yield of the land surface was 158 000 gal. per day in October, 1910, and 205 000 gal. per day in July, 1913, the loss

by evaporation was enough greater in the latter month to make the yield of land and water surfaces combined smaller. The computations giving this result are as follows:

October, 1910.

95 per cent. of 158 000 gal. daily — the yield of a square mile of land surface — equals	150 100 gal. daily.	
5 per cent. of —986 000 gal. daily — the yield of a square mile of water surface — equals	—49 300 gal. daily.	
Net yield of land and water surface combined equals		100 800 gal. daily.

July, 1913.

95 per cent. of 205 000 gal. daily — the yield of a square mile of land surface — equals	194 800 gal. daily.	
5 per cent. of —2 025 000 gal. daily — the yield of a square mile of water surface — equals	—101 300 gal. daily.	
Net yield of land and water surface combined equals		93 500 gal. daily.

The corresponding yields per square mile of combined land and water surfaces, when the water surfaces amount to 10 and 15 per cent. of the whole area, are as follows:

	Gallons Daily.	
Month.	10 Per Cent. Water Surface.	15 Per Cent. Water Surface.
October, 1910	40 600	—13 600
July, 1913	—18 000	—129 500

For periods covering more than one month the same general method is employed, the yield of water surfaces being determined as the difference between the aggregate evaporation and the aggregate rainfall for the whole number of months.

In some cases a period which would give the minimum combined yield of land and water surfaces for one percentage of water surfaces would not give the minimum yield for other percentages. For instance, in the case of the three months' period, the minimum

yield with 5 per cent. of water surfaces occurred from July to September, 1913, while with 10 and 15 per cent. of water surfaces the minimum yield occurred from July to September, 1912.

Having obtained the minimum yield of the combined land and water surfaces for periods of all lengths, the required storage capacity for the last three columns of the table was computed in the same manner as that for the second column of the table, as already described.

DISCUSSION.

MR. ALLEN HAZEN.* Collecting the records of run-off of streams in very dry periods and putting them in convenient and serviceable form is a useful and necessary work. As I had the honor of appointing this committee, I think I may claim some of the credit for the excellent work that has been done by it.

When Mr. Stearns, chairman of the committee, wrote his report on Water Supplies in Massachusetts, which was published in the annual report of the State Board of Health for 1890, and showed the principles of computing the storage required to maintain desired flows, I think it was generally conceded that the subject was well cleared up for Massachusetts at least, and that the amount of water that could be obtained from a given area could be determined, as well as the size of the reservoir needed to make it available; but as years have gone by it has become apparent that other factors would have to be taken into account. The experience of the past few years, so well set forth in this report, serves to emphasize the divergence from the early standards.

There are a few matters in regard to the report that I wish to mention. In the first place, all the figures in it are computed from the average monthly flows. There is often a substantial difference between the storage computed from the average monthly figures and that which is actually required, depending upon the daily flows. One who has not made a comparison will be surprised at the difference. The difference is not constant. Sometimes it amounts to hardly anything; sometimes to a large figure. Whether it is large or small depends mainly upon whether the

* Civil Engineer, New York City.

storm that breaks the drought occurs in the first or last part of the calendar month in which it happens. This is a matter of pure chance. The tables representing required storage in the report of the committee represent altogether thirteen records of dry periods of different streams, running from a few months to several years. It would be interesting and I think profitable to go through the data again on a daily basis, so that the results entered in the table would rest upon actual daily results and not upon monthly averages. In the case of the smaller rates of draft it would be found that this procedure would sometimes double the amount of storage indicated. In the case of the higher rates of draft the difference would be less relatively, but still important. The committee mentions the fact that monthly averages were used, and that results from daily flows would be greater, but does this in a general way and without bringing it into the tables; and so the tables at present show less storage than would actually be required.

In addition to the storage provided in a reservoir, it frequently happens that the interstices of the soil hold water and give it up slowly and so provide additional storage. This may be called "ground-water" storage. The amount of ground-water storage varies greatly on different catchment areas. It is difficult to study adequately the amount of storage that must be provided in a reservoir without also taking into account the natural or ground-water storage. For the natural storage as far as it goes is just as useful as reservoir storage and reduces the required capacity of the reservoirs. For instance, in the Wachusett area, in some studies recently made, the conclusion was reached that the ground-water storage is sufficient to maintain the supply with a given draft for sixty days longer than the storage in the reservoir would suffice to maintain it if there were no ground-water storage. In the case of some other New England streams, there is practically no ground-water storage. It will be difficult to fully understand storage requirements and to adequately compare one stream with another without in some way taking this ground-water storage into account.

Mr. Stearns has stated the probability that the records accumulated by the committee do not show the driest years that are to be expected upon the several streams, but that still drier

times may be expected. I would put it more strongly, and say that drier times are sure to come. In the case of two streams having the longest records, the committee places side by side the storage requirements for the driest and for the second driest periods; and it is interesting to note that in general terms, and without going into refinements, the driest period on each called for a storage of something like fifty per cent. more than that required to maintain the same draft through the second driest one. In other words, the second driest spell recorded in each case called for only two thirds as much storage as was required to maintain the same output in the driest one. In my judgment, it is only a question of time when droughts will occur so much more severe than those reflected by this record that the amount of storage entered in these tables will be exceeded by another fifty-per cent. Even that is not the limit. It is only a question of how long it will be until still drier periods occur.

The practical question comes as to the use of these tables that the committee has prepared. For the last twenty years much use had been made of records reflecting dry periods of about thirty years ago. Now it appears that, judged by the records of several of the streams, there has been a still drier period. The logical result of consideration of the figures now presented seems to be to mark off from ten to twenty per cent. of the supposed capacities of the water supplies which are re-rated by these records. In other words, a supply supposed for the last twenty years to be capable of furnishing 10 million gallons per day is now going to be marked down to nine or even to eight million gallons per day. We have a new basis, to be used presumably for a certain term of years, until there is a still drier time; and then, following the matter to its logical conclusion, we may expect to have a new and still lower basis of rating than the present one.

The speaker suggests that it is possible, by considering the records of all the years, to form an idea of the nature of the series which they form and of the probabilities of the recurrence of years of given degrees of dryness. The amounts of water that are required in each year to maintain a certain assumed rate of draft from any supply can be easily calculated from the flow records, and these form a never-ending series of quantities. The values

go up and down from year to year, and never repeat themselves. These variations at first sight appear to be purely accidental and outside the range of mathematical calculation; but on study it is found that they can be understood, and that they do have a law and follow it, and that law is in a general way the law of probabilities which is explained in the various text-books on statistics. It is possible, taking the matter up in this way, to use all of the information that is available about the flow of a stream to throw light upon the character of the indefinitely long series of which its record forms one part, and to consider this in connection with similar records of other streams more or less similar to it, to form an idea of the probable frequency of the recurrence of the periods of given degrees of dryness.

The method of rating streams and storage which has been followed by our committee is a method that has been practically in universal use up to the present time. It is based upon the tacit but erroneous assumption that the dry periods of the past will be repeated from time to time in the future.

I have compared the tables prepared by the committee with studies recently presented to the American Society of Civil Engineers for some of the streams for which full data were available; and in a general way, judged by probability methods, the driest years recorded by the committee correspond to what I have otherwise called the ninety-five per cent. dry year. That is to say, in an indefinitely long series of years, about ninety-five years in one hundred may be expected to yield the stated quantities with smaller drafts upon the storage than are shown upon the tables, while the other five years in a hundred will require more storage. In other words, the supply will fall short about one year in twenty.

The subject is an extremely interesting one, and one that furnishes an opportunity for most painstaking study; and I feel that it is one that we shall know more about in a few years than we do now. At the present time this contribution to the really fundamental underlying data is the most important that has been made in this country or any where, and I think the committee is to be thanked most heartily for its work.

MR. J. M. DIVEN.* The figures of average rainfall given by the committee for twenty- to forty-year periods agree with the speaker's experience. These records show an average considerably above those made for a term of years running back, say, for ten years. This leads one to wonder if the older records were correct, if they did not err due to the lack of proper measuring devices. If the records are correct and the amount of annual rainfall is gradually growing less, does it not mean trouble in the future? Evidently calculations based on long averages will not be reliable if the records of earlier years of the period are not correct, or if the rainfall was considerably above what we can expect now.

MR. THEODORE H. MCKENZIE.† Mr. Chairman, I was very much pleased to notice the accuracy and honesty of Mr. Stearns's statements and diagrams with reference to the run-off of different watersheds, and particularly with reference to the matter of the run-off of the Esopus watershed. I have been engaged on a great many cases on that watershed in the employ of claimants.

Most of the engineers engaged for the city have been Massachusetts men, and it has been very difficult to convince them that there was any more run-off there than in the Sudbury and some of the other Massachusetts watersheds, where the ground is sand and gravel, and where the woods have been cut off and the evaporation is large. On the Esopus shed the slopes are precipitous and rocky, with the rock near the surface, and the country well wooded, and also on both sides of the stream the mountains are so high that the sun doesn't get access to the water in the early morning or late afternoon, and the evaporation is necessarily much smaller than on many of the Massachusetts watersheds.

MR. H. K. BARROWS.‡ Our knowledge concerning one of the factors considered in the report of the committee, viz., that of evaporation, is very much less complete than could be wished. The committee have used for data of evaporation from water surfaces the records obtained by Mr. Desmond FitzGerald, which were based upon experiments made at Chestnut Hill Reservoir, near Boston, covering the period 1875–1890.

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†Consulting Engineer, Hartford, Conn.
‡Consulting Engineer, Boston, Mass.

Mr. FitzGerald's experiments were carefully made, the results are accurate and can be used in estimating evaporation where conditions are similar to those at Chestnut Hill, where the records were obtained. We know, however, from measurements of evaporation that have been made in other parts of the country and in other parts of New England, that variation in evaporation from water surfaces in different localities may be very considerable from the figures obtained by Mr. FitzGerald.

In the footnote on page 409, the committee refer to certain measurements of evaporation that were made by the United States Geological Survey between 1905 and 1908, which are published in detail in Water Supply Paper No. 279 of the United States Geological Survey. The average annual evaporation at these Maine stations is a little less than 26 in., as compared with about 39 in. at Chestnut Hill, as found by Mr. FitzGerald. Evaporation experiments at Rochester, N. Y., which began in 1891 and are still in progress, show a mean annual evaporation of about 33 in.

The evaporation for any given month at a given locality does not vary very greatly from year to year, and consequently a few years' observations of evaporation will serve very well in defining the average evaporation to be expected during a given month or during the year.

The measurement of evaporation directly, as described in Water Supply Paper No. 279, is not a matter of great difficulty, and the speaker would like to suggest that such measurements might well be undertaken by water-works departments where large reservoirs are an important part of the water-supply system. The apparatus required is not complicated, and measurements can be made by persons in connection with other regular duties at the reservoir.

Where the percentage of water area in a catchment basin is small, the relative effect of evaporation becomes of less importance, and under such conditions existing data similar to those obtained by Mr. FitzGerald and others will suffice. On the other hand, there are many reservoirs whose area of water surface is a large percentage of the total drainage area. Under these conditions it is important to be able to allow for evaporation more accurately than can be done by the use of general data. Under such condi-

tions it would be well worth while to make measurements of evaporation for a few years, thus obtaining data applicable to the local situation.

MR. ROBERT E. HORTON* (*by letter*). The report of this committee deals with the available supply of the raw material, — water. Its work is of great value and its report is elaborate. In reading it, it has been found with disappointment that data was collected regarding so few drainage basins. The writer had sincerely hoped that the work of the committee would include the collection of a mass of data giving the natural minimum yield, if only for a few days in each case, of a large number of small watersheds, such as are commonly used as sources of gravity water supply in New England. As the writer will point out, methods of estimating the minimum or safe reliable yield of such streams, based on considerations of rainfall only, cannot be relied upon in such cases. In the writer's opinion, the method of estimating minimum yield from rainfall, outlined by the committee, should be used with extreme caution where the drainage area involved is less than ten square miles, at least. Furthermore, it seems to the writer that the calculation of the minimum flow of streams from the simultaneous rainfall is to a certain extent attacking the problem from the wrong angle. The minimum flow of streams occurs during periods when there is little or no effective rainfall. The problem may be stated in this way: What will the yield be after a period of a certain length of time in months or days with no effective rainfall? Rainfall enters only as a time element in the problem as fixing the duration of the period during which the supply of the stream must come from other sources than direct rainfall. That is, it must come from previously stored precipitation in some form:

1. Surface storage in lakes and marshes, or accumulated snow and ice in winter.
2. Stream channel storage, an item commonly overlooked.
3. Ground-water storage.

Stream channel storage often represents a combination of surface and ground-water storage. Even where a stream is above the general ground-water level, water alternately flows out of the

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stream into the adjacent soil and from the soil into the stream as the stream rises and falls. In the case of Mohawk River, the writer estimates the volume of channel storage in the prism of the main stream and its tributaries, represented by a fall of the stream from bank-full to low-water stage, to be at least two billion cubic feet. This channel storage runs off very rapidly at the start, but more and more slowly as time goes on and as it is more and more augmented by ground-water return from the adjacent banks. It is the writer's observation that channel and adjacent bank storage, excluding ground-water supply in the ordinary sense, is often the controlling element which determines the yield of many small streams during periods of no effective rainfall.

For streams having extensive sand deposits on their drainage basins, ground-water is the controlling element as regards yield during periods of deficient rainfall. For such streams the writer has known the yield to exceed the rainfall during dry summer months. Again, the writer has found for such streams that a knowledge of ground-water level, say on July 1, is a good index of what the yield of the stream will be if there is no effective rainfall during subsequent weeks. The writer regrets that the committee did not attempt to determine the ground-water conditions during the drought in question for the different watersheds studied. These data are very easily obtained where there are unused open or dug shallow wells. Weekly measurements to water surface in each of two or three such wells in a small drainage basin will usually give satisfactory data.

There is a law which governs the relation between duration of drought and flow for natural and unregulated streams. Theoretical and experimental researches by the writer indicate that this law can be determined approximately for many streams from gagings taken during a period of no rainfall for a comparatively short length of time. For the simple case of a stream supplied exclusively from ground water to which there is no accretion during the period of drought, the law of yield of the stream is apparently identical with the "law of natural exhaustion," which runs through a wide range of physical relations between time and quantity, in much the same way as the law of inverse squares is a common relation between distance and quantity.

In its simplest form, —

$$q = q_0 e^{-ct}$$

where q_0 and q are the yield or flow of the stream at the beginning and end of the time t, respectively; c is a constant; e is the base of the Napierian logarithms. This formula requires modification in case of streams deriving their supply during periods of no rainfall from two or more sources, as, for example, from ground water and surface lakes combined. It also requires correction where the ground-water table receives accretions from capillary water in the surface layers of the soil, as is commonly true for quite a long period after the last rain. It is presented here to illustrate a method believed to be new, and a law hitherto apparently overlooked, by which the yield of streams in the absence of rainfall can be estimated more rationally than by attempting to estimate from rainfall, — the one thing which is not there.

The committee discards the Catskill streams, in part, after some discussion of possible causes for the apparently higher run-off than that for New England streams. The writer feels obliged to say that in his opinion the committee has missed an important part of the true explanation. It may be true, as the committee suggests, that the measured yield of Schoharie Creek is somewhat too large during winter periods owing to ice obstruction, but the writer does not believe this is the cause of any serious error in the Esopus Creek records. Since the year 1906 the flow of Esopus Creek has been determined from a well-constructed concrete weir, using coefficients derived from experiments on a similar full-sized model section. The stage of the stream is taken by a recording gage. The writer has made inquiry and is informed that the weir has been kept clear of ice obstruction, with few exceptions for short periods, chiefly during the month of February, and for these periods a reduction, probably adequate, has been made in calculating the discharge. The records taken at this weir agree substantially with parallel records at current meter stations where very numerous measurements were made through the ice to determine the winter flow.

The writer believes that the deficiency in catch of the ordinary rain gage during snowstorms, especially on mountains and in

strong winds, is a very common cause of the discrepancy between observed precipitation and run-off during winter months. The writer has measured snow on the ground in woods in March or early April equal to the entire recorded precipitation for the winter.

There is another factor commonly overlooked heretofore in studying differences in the yield of drainage basins, and that is the run-off of the basin in relation to prevailing wind direction. Omitting polysyllables and using proverb language, "The windward side of the roof catches the rain." Esopus Creek drains part of the southeast slope of the Catskills. The prevailing rain-producing winds come from the southeast. The drainage basin is very precipitous, — the average slope of the landside above Esopus Weir, as determined from the United States Geological Survey topographic map, is 13 degrees 50 minutes. If rain fell vertically, a sloping area would catch the same amount as a flat area of equal horizontal projection, but rain seldom falls vertically. If the rain is deflected by the wind an average of 10 degrees west from the vertical, a little calculation will show that the drainage basin would catch 3.9 per cent. more rain than a flat area of equal size. This increased catch of sloping drainage basins owing to deflection of rain from the vertical is independent of and should not be confused with the increased rainfall sometimes resulting from the upward deflection of wind currents blowing against mountain slopes.

As a further indication that the failure of the Catskill streams to flow in accordance with the categorical and time-honored custom of the Croton, Sudbury, Cochituate, and other New England streams, the writer cites the case of West Canada Creek which, as measured at four different gaging stations, — three of them current meter stations and the fourth having a good concrete dam used as a weir, — has repeatedly shown winter run-off in excess of the measured winter precipitation.

The writer feels that the footnote at the bottom of Table No. 23, page 447, is certainly incomplete and probably in error.

In its conclusion, No. 9, page 469; also on page 431 and page 458, the committee has made statements, perhaps inadvertently, which seem to lead to the conclusion that precipitation always increases with altitude. This is generally true only when there is

more than a certain minimum difference of elevation and when the prevailing rain-bearing winds blow toward the slope. It is true as regards Esopus Creek, but is not true generally in the Adirondacks, since there the precipitation on the westward slope is greater than at higher elevations toward the eastern slope.

The committee estimates the yield of swamps on the basis of 40 per cent. equivalent water surface if undrained, and 30 per cent. if drained. This rule is no doubt correct for some cases, and may approximate the average case. The words "swamp" and "marsh" — the former applying to areas wet but not usually submerged; the latter to areas usually submerged but containing trees or other aquatic vegetation — cover the whole range from open water to dry land.

It is probable that the evaporation loss from swamps, especially those containing the characteristic protruding humps known as "bogs," is generally greater than from open-water surface. The writer would be inclined to think (unless convinced to the contrary by experimental evidence) that the evaporation loss from timber-covered swamps or from marshes filled with reeds and rushes, such as the great Montezuma Marshes in central New York, would also be greater than from open-water surface. If the writer's hypothesis is true, then the whole area of perpetually wet ground with vegetation should be treated as water surface *with an increased evaporation.*

The points raised by the committee as to the relation between elevation and run-off are interesting and, to some extent, at least, new. The report of the committee implies, if it does not directly state, that owing to lower temperature at higher altitudes, the evaporation is necessarily less than it would be at lower elevations, other things being equal. The statement of the committee, on page 409 of its report, as to relation between elevation and evaporation, is incomplete. Evaporation, approximately at least, is a function of the difference between the maximum vapor pressure corresponding to the water temperature and the actual vapor pressure in the atmosphere. Mean temperature decreases about 1 degree Fahr. for each 300 ft. altitude. The maximum vapor pressure decreases with the temperature, and hence with the altitude, and the absolute vapor pressure in the air also decreases

with the altitude. Since both factors governing evaporation decrease with altitude, their difference may either increase or decrease according to their relative rates. The committee has formulated empirical relations between annual precipitation and run-off which may be more or less useful. The rule used by the committee in preparing Table No. 5, page 416, is equivalent to the assumption that 70 per cent. of all rainfall in excess of 40 in. reaches the stream, and that 65 per cent. of all rainfall between 35 in. and 40 in. reaches the stream. It would be more logical to use a sliding scale of percentage of rainfall for rainfalls between 35 in. and 45 in., which would give the same results for these particular values and intermediate results for intermediate values. On this basis, the rule of the committee for estimating annual run-off may be reduced to the following forms:

$$y = 870\,000 + 47\,613(P - 40)\,\frac{30+P}{100}; \tag{1}$$

$$\text{or, } y = 870\,000 + 476.13(P^2 - 10P - 1\,200); \tag{2}$$

$$\text{or, } y = 308\,644 - 4\,761.3P + 476.13P^2. \tag{3}$$

y = Average annual yield per day, U. S. gallons per square mile.

P = Precipitation, inches.

R = Run-off depth, inches.

$$R = 18.27 + (P - 40)\frac{30+P}{100}; \tag{4}$$

$$\text{or, } R = \frac{P^2}{100} - \frac{P}{10} + 6.27. \tag{5}$$

Recalculating Table No. 5 by formula (1), above given, tends to reduce the differences between the observed and computed values, and also tends to equalize the sum of the plus and minus departures, thus indicating a somewhat more consistent result. The sum of the plus departures is much greater than that of the minus departures, indicating that the formula is conservative and gives less than the probable average yield. In order to equalize the plus and minus departures so as to obtain the most probable value of the yield, the constant should be taken as 916 000 gal. instead of 870 000 gal., as given by the committee.

The practice was formerly common of applying the Croton, Sudbury, or Cochituate run-off records as "standards" in esti-

mating the yield of all sorts, sizes, and conditions of drainage basins in New England and elsewhere. The methods, charts, and tables furnished by the committee are in effect a modification of this "standard" run-off method, but afford some material improvement in that the number of stream-flow records offered as a basis of selection is relatively large. It does not appear, however, that the problem of greatest importance, namely, the derivation of rational methods of estimating the natural minimum yield of small drainage basins during periods of drought of less than one year has been covered by the report of the committee, and it would seem to the writer proper to extend the work of the committee along these lines.

Yield of Watersheds.

MR. X. H. GOODNOUGH.* The study of the principles of estimating the storage required to produce a desired yield from a given watershed is a comparatively new one, the first paper on the subject in this country having been presented by Mr. Stearns in the annual report of the State Board of Health in 1890. Up to that time, and for several years thereafter, the observations on the Sudbury River and the Croton watersheds formed the basis of the computation of the yield of most watersheds in New England and its immediate neighborhood. Since then the careful measurement of the flow of streams has been undertaken at other places, but the number of available observations is still a limited one.

The instructions to your committee were to investigate the yields of New England watersheds, and such other watersheds as the committee might deem desirable, during the present dry period, i. e., during the period beginning with 1908. Under these instructions the committee has sought to present actual facts as to the yield of the watersheds in which careful measurements have been made, together with such conclusions as the committee found it practicable to draw therefrom as an aid in solving questions of watershed development arising in the every-day work of the water works engineer and manager.

* Chief Engineer, Massachusetts State Department of Health.

The watersheds vary greatly in character, and the amount of work required to secure satisfactory observations is in most cases considerable. The observations are in nearly all cases kept by calendar months, and this unit was found the most convenient one to use in the study of the results. Where watersheds are developed to the extent commonly found in New England, calculations of yield commonly cover a period of many months, and errors due to the use of monthly records become relatively insignificant. The calculations have included corrections for natural storage and estimated corrections for swamp. They do not include corrections for storage in the ground within the watershed.

Variations due to ground-water storage may be very great, especially in small watersheds. The watershed of Muddy Pond Brook, for example, used as a source of water supply for the town of Stoughton, which has an area of only about 1.1 square miles and contains no natural or artificial storage of any consequence except in the ground, maintains a flow in the stream running out of the watershed which is ample at all times as a water supply for 6 000 people.

During the past summer, in making examinations for a water supply for Salisbury, a stream was found in the northerly part of the town flowing at the rate of 300 000 gal. per day per square mile from a watershed of about half a square mile. The watershed consisted of rolling, sandy country containing no ponds or reservoirs and only about one or two acres of swamp. On the same day the flow of the Ipswich River at a point where its drainage area is 73 square miles amounted to 22 000 gal. per square mile. Probably 20 per cent. of the watershed of the Ipswich River above the point of measurement is swamp land, while the ponds and reservoirs on this watershed are insignificant. These instances are given to show the wide variation which may occur in the natural flow of streams due to ground water storage.

On the Neponset River there is a large amount of underground storage about the great meadows which runs out upon the meadows and keeps large areas of them constantly wet, yet most of this water is evidently lost by evaporation in the drier portion of the year, since the flow of the stream falls at times to very low quan-

tities. If these meadows were provided with drains through which the ground and surface water flowing upon the meadows could find its way quickly to the main river, there is no doubt that the dry-weather flow of the latter would be considerably increased.

Under the conditions found in New England, including the wide variations in the water capacity and yield of the porous strata, it is impracticable to measure ground-water flows in large areas, or even in small areas, without expensive tests. A very fair idea of the probable amount of this ground-water flow can be obtained in some cases, especially in streams draining watersheds containing considerable swamp, by inspection and also by analysis of the water, since in very dry periods when the yield from the swamps ceases, the character of the water of the stream will change greatly if it receives considerable ground water, and the color and organic matter found in the water in ordinary years will become greatly reduced.

Lack of knowledge of ground-water storage unquestionably affects somewhat the yields of the streams examined, and in applying these yields to other streams possible differences due to this cause must be taken into account. Where the period considered is a short one, ground-water storage may be a considerable item in the account, and the writer has had experience, with ponds which, when drawn down, yielded water in considerable excess of the measurable storage in the reservoir itself, and in one case the measurements indicated a storage in the ground amounting to 25 per cent. in excess of the storage of the reservoir. This of course means that the reservoir was surrounded in part at least with very porous soil extending to a considerable depth. Even allowing that the soil was extremely porous, the added reservoir in the ground must have had nearly the same size as the clear capacity of the pond itself when the fact is taken into account that this added reservoir was filled with gravel. Errors of this character largely disappear when the storage development of the watershed is high and a long period is taken into account, and when the area of the watershed is large they are seldom of much effect, but in any case it is usually practicable, after careful inspection and with the aid of experience in the yield of ground waters, to form a fairly accurate judgment as to how much allow-

ance may reasonably be made in a given case for ground-water storage.

In making the observations of the yield of watersheds, the usual method is of course to measure and make allowance for the quantity flowing out of it through its natural outlet, the quantity withdrawn in various ways, and the gain or loss of storage. The result of these computations is often a minus flow when short periods are taken into account, and where the area of water surface is large the minus flow may cover a period of several weeks or even months. This does not of course mean that when the observed yield is a minus quantity the stream ceases to flow. It means simply that the total quantity of water flowing from the land surfaces into the ponds or swamps at such times is lost by evaporation.

Where no water is withdrawn from a watershed and there are no reservoirs upon it, it is a simple matter to gage the stream by means of a weir and thus determine its minimum flow, and this method may be followed even when the flow of water is regulated somewhat by storage.

Some of the complications that may arise in measuring the flow of a stream are illustrated by the case of Lake Quannapowitt at Wakefield, surveyed during one of the recent dry years. The lake has an area of 230 acres, or .36 of a square mile, and its watershed excluding the lake is 3.97 square miles. It contains nearly all the thickly settled portions of Reading and a considerable portion of Wakefield. In the former town 250 000 gal. of water per day are brought into the watershed to supply the inhabitants with water, and, as there are no sewers, this water is discharged into the ground and much of it finds its way to neighboring water courses, judging from the results of their chemical analyses. These water courses, which flow into Lake Quannapowitt, in most cases contain water at all seasons of the year. In Wakefield, also, much water is brought into the watershed from outside, while, on the other hand, water is carried out by sewers, which do not, however, extend to all the portions of the watershed in Wakefield supplied with water.

While there was a flow in all the streams entering the lake at the time of the examination, there was no flow in the stream

running out of the lake, and at the outlet the water of the lake had fallen considerably below the bottom of the outlet channel in the latter part of 1909,— that is, the evaporation from the lake and the amount of water carried out by the sewers more than counterbalanced the yield of the watershed plus the water brought in by the water supplies, and this lake has a minus yield for a period of several months in dry seasons.

In case of ground-water storage, which it is of course impracticable to measure, it may be said that this storage is practically never exhausted and probably enters the streams at a fairly regular rate, though the flow may constantly grow less through a very long period.

The committee has endeavored to present something practical, and, in view of the extensive use made of the earlier studies relating to the flow of streams, and especially the Sudbury and Croton rivers, in the past, it is believed that these observations kept by water works men in New England and its neighborhood will prove of added value in the study of the yield of watersheds. They cannot be applied indiscriminately but, used with judgment, they should make it practicable for the engineer to determine quite closely in most cases the probable yield which can be secured with given storage on a given stream in the larger part of New England and eastern New York. In thus applying the records, full consideration must of course be given to other circumstances, such as the situation of the city or town to be supplied and the ease or difficulty of obtaining an emergency additional supply in case of the exhaustion of the regular source.

It is usually an easy matter to secure an additional supply of good water amounting to 50 000 or 100 000 gal. per day, and it is usually not a difficult matter to obtain a temporary supply of 200 000 or 300 000 gal. per day. With larger supplies the difficulty of securing a suitable auxiliary supply increases; but, since in practically all cases the larger surface water supplies in New England and eastern New York are obtained from storage reservoirs, observations of the decrease in the quantity of water in storage will, studied in connection with these records, give ample warning of the possible danger of shortage and afford an opportunity to provide against it either by an enforced reduction in

the consumption of water or the introduction of an auxiliary supply. There is often a sanitary question involved in the maintenance of ample storage, since long storage is one of the most potent factors in the destruction of disease-producing organisms which may enter a water supply and also in the improvement in the quality of the water in other respects.

It is hoped that one advantage which the Association may derive from the presentation of these studies will be that the increased interest aroused in this subject will lead to the establishment of a greater number of observations of rainfall and stream flow in various parts of New England, thus furnishing additional data which will be of great value, especially when compared with the information here collected.

The following table is similar to Table 30 on page 466, and gives the minimum flow of certain drainage areas in gallons daily per square mile for periods ranging from one week to three months.

Drainage Area.		Year.	Period.				
Name.	Square Miles.		One Week.	Two Weeks.	One* Month.	Two† Months.	Three‡ Months.
			Million Gals. per Day.				
Ipswich River at East Street, Middleton	73.02	1911	.024	.029	.069	.120	.150
		1912	.037	.046	.058	.083	.109
		1913	.011	.014	.031	.042	.059
		1914	.006	.006	.010	.015	.030
Ipswich River at Willowdale	119.9	1911	.058	.060	.094	.164	.196
Charles River at Charles River Village.....	184.0	1914	.137	.146	.151	.163	.180

*One month=driest period of 30 consecutive days.
†Two months=driest period of 60 consecutive days.
‡Three months=driest period of 90 consecutive days.

In making the measurements given in the above table, no allowance has been made for storage. Storage on the Ipswich River is practically insignificant except for the temporary storage in swamps. The percentage of swamp area on this river is very large, and the swamps are of such a character that they do not drain freely into the river. In the watershed of the Charles

River the amount of storage, while larger than on the Ipswich, is not great. There is a very large area of meadow land in the watershed of this stream, but the extensive meadows above Medfield are for the most part considerably above the level of the river in dry periods. There are extensive deposits of sand and gravel in the valley of this stream above the point of measurement, which no doubt have a considerable influence in maintaining the dry-weather flow.

Table 4 on page 414, entitled "Comparison of Run-Off in Years of High and Low Precipitation," shows that on the Wachusett watershed 77 per cent. of the excess of precipitation in the highest four years recorded over the lowest four years ran off into the stream. Similarly on the Sudbury watershed, comparing the highest six years with the lowest six years, it appears that 82.9 per cent. of the excess in wet years ran off into the streams.

If, instead of considering the entire year, the wettest six-month periods in each year only — that is, from December to May inclusive — are compared, it will be found that a still larger per cent. of the run-off is collected into the streams when the precipitation is large than when it is small. The results of this comparison are shown in the following table, both for the Wachusett and Sudbury watersheds.

Drainage Area.	Period.	Average Precipitation. Inches.	Average Run-off. Inches.	Per Cent of Run-off.
Wachusett (December to May inclusive) ..	Highest 4 yrs.	28.09	21.929	78.1
	Lowest 4 yrs.	17.51	11.920	68.1
	Difference	10.58	10.009	94.6
Sudbury (December to May inclusive) ..	Highest 6 yrs.	28.65	21.568	75.3
	Lowest 6 yrs.	17.66	10.843	61.4
	Difference	10.99	10.725	97.6

The foregoing table shows that in the wetter portion of the year the run-off from the difference between the precipitation of the highest and lowest years is, on the Wachusett watershed, 94.6 per

cent., and on the Sudbury watershed, 97.6 per cent. of the rainfall.

The following table gives a similar comparison of the average run-off for the years of highest and lowest rainfall in the months from June to November inclusive, the drier part of the year.

Drainage Area.	Period.	Average Precipitation. Inches.	Average Run-off. Inches	Per Cent. of Run-off.
Wachusett (June to November inclusive)	Highest 4 yrs.	29.44	10.111	34.3
	Lowest 4 yrs.	16.04	2.480	15.4
	Difference	13.40	7.631	56.9
Sudbury (June to November inclusive)..	Highest 6 yrs.	30.26	9.047	29.9
	Lowest 6 yrs.	14.83	.708	4.8
	Difference	15.43	8.339	54.0

This latter table shows that 56.9 per cent. of the excess of rainfall in the period from June to November inclusive, is collected in the streams on the Wachusett watershed, and 54 per cent. on that of the Sudbury.

MR. WILLIAM S. JOHNSON.* Mr. Chairman, there is no question that this is a very valuable report and will be of great use to many of us. There are one or two points which I would like to bring up, concerning which I at least would like further information.

Many of our watersheds contain a large proportion of swamp area, and the yield of these areas is an important part of the total yield. Mr. Stearns and Mr. Goodnough know more about this than almost anybody else, and I have no doubt that their conclusions are correct, but I think it would be of interest to many of us to know how they arrive at the percentages which they use, whether they are based on measurements, or are simply a matter of judgment. I have been brought up to believe that the yield of a swamp was very much less than the yield of a corresponding water area during the summer months. Meadow grass, we are

*Consulting Engineer, Boston, Mass.

told, will use up while growing from thirty to forty inches of water, provided it can get it. Those of us who have waded around in swamps on a hot, sunny day know that the water in a meadow exposed to the sun is very much warmer than the water in a pond or a stream even on the surface, and that would favor evaporation. So that I always supposed that if you add the large amount which is used up by the meadow grass in growing, and that which evaporates directly into the air, the evaporation would be very much greater than it would from a water surface. In the winter months, of course, the conditions are quite different and there would be a difference between open meadow and alder swamps. Some of our watersheds, like that which Mr. Goodnough referred to, the Ipswich River, contain enormous areas of meadows, and it is very important to know something about what the yield of such areas is.

The other matter is that of evaporation. Of course everybody uses the classic results of Mr. FitzGerald's experiments. The committee says that the average monthly results may be used without serious error, because the evaporation for a given month in different years does not vary very much. As I remember Mr. FitzGerald's experiments, there was a very considerable difference in the evaporation in different years, and if you are considering the yield of a pond with a water surface as large or nearly as large as the land surface, this difference in the evaporation enters into it very seriously. I remember that the total evaporation for a year varied about thirty per cent., and I have run up against that in several rather important cases, where it was important to know what the yield of the water surface was. I have been somewhat embarrassed in trying to maintain my position based on the average results of these evaporation experiments, because of the considerable variation. To use the average did not seem quite right even to my own mind, and to those on the other side of the case it seemed very far from right.

Mr. Frederic P. Stearns.* Replying to Mr. Diven's remarks, the average rainfall for the last ten years is, as he states, considerably less than for the last twenty and forty years. The result is not due to incorrect records, as the measuring devices in use forty years ago were excellent and the records were kept with

*Consulting Engineer, Boston, Mass.

care. If one had only the records for the last forty years, it might be reasonable to infer that the rainfall was diminishing, but there are good records of rainfall extending back to 1820, and still more extending back to 1830, which show that there were probably drier periods in the first half of the last century than in recent years. These older records may not be quite as accurate as recent records, but they are sufficiently trustworthy to prove that there were periods of as low, if not lower, rainfall eighty or ninety years ago than recently.

Mr. Hazen has called attention to several matters which should be considered in the practical use of the tables, and it is well that these features should be emphasized. The committee fully recognized that the tables and diagrams might be improperly used in the manner which he has suggested and in other ways, and has attempted to prevent such use by explaining the conditions and character of the records upon which the tables and diagrams were based, and under the head of "Caution" has explained the various inaccuracies which might result from unintelligent use. Under this head one reference is to the inaccuracy due to basing tables on monthly instead of daily yields, a matter which has been brought up by Mr. Hazen, and the recommendation is made that this be offset by providing storage equal to a month's supply of water in addition to the amount of storage indicated by the use of the tables.

Mr. Hazen has suggested that it might be interesting and profitable to go through the data again on a daily instead of a monthly basis, but this cannot be done with the data collected by the committee, because the records furnished were on a monthly basis. The committee gave this matter consideration at the beginning of the investigation, and concluded that it would be more likely to get practical results if it asked for the records of average monthly instead of daily flow. It seemed that more would be lost than gained by attempting such a refinement.

The ground-water storage is in some cases, as Mr. Hazen suggests, a valuable addition to the visible storage. The records obtained from each stream necessarily represented the flow as affected by the ground-water storage of the drainage area in general, and the ground-water storage around the margins of

reservoirs to the extent that it was drawn upon by the lowering of the water in the reservoirs. Such records are, therefore, directly applicable to the drainage areas from which they are derived, but in deducing the yield of one drainage area from the yield of another, this matter should be taken into consideration. When the drainage area is fully developed, so that the storage is sufficient to equalize the flow of a stream for a series of dry years, this feature is one of minor importance.

The point that has been raised that there may be much drier years than those included in the recent dry period is one with which the speaker agrees, and it seems reasonable to assume that the driest year of the recent period represents what Mr. Hazen has called the "ninety-five per cent. dry year"; so that five years in a hundred will be drier.

Judging from past experience, more than one of these years are likely to come in dry periods, so that at times they may be only two or three years apart, like the dry years 1880 and 1883; and at other times there may be an interval of thirty or forty years between such extremely dry years.

The recent period has been remarkable in including not only an extremely dry year but a long series of *consecutive* dry years, and such a series is not likely to recur nearly as often as the individual dry year. From the information now available, it seems unlikely that such a series will recur more frequently than once in a century.

When a source of supply is highly developed by ample storage, its safe capacity is based upon the yield in a series of consecutive dry years, and for such sources the yield based on the recent dry period will be very conservative. With a smaller development of a source, so that its safe capacity is based upon the yield of a single year, it is much more important to take into account the probability of still drier years.

Mr. Hazen has made the suggestion that, as the safe capacity of sources of water supply based on the recent dry period is from ten to twenty per cent. less than one based on the dry period of about thirty years ago, we may expect in future years to have a new and still lower basis of rating than the present one. Referring to this suggestion, the speaker wishes to emphasize the

point made in the report that the safe capacity of a given water supply is to a large extent a question of practical judgment and not a fixed quantity as set forth by tables and diagrams.

A city which is depending upon the natural flow of a stream, or upon a storage reservoir which may be exhausted during the dry period of a single year, should reckon the safe capacity of its source on a basis of much drier years than have yet been recorded, unless it can obtain an additional emergency supply in a short time. It is not good policy to provide for those things which happen only once in from twenty-five to fifty years when the expenditure of a moderate amount of money can meet the emergency if it comes.

On the other hand, a large city which cannot obtain an emergency supply at short notice should be very conservative when determining the safe capacity of its sources.

To use Mr. Hazen's nomenclature, one city should base the safe capacity of its sources on a 98 or 99 per cent. dry year, while another may have its water supply equally well guarded against failure if it bases the safe capacity on an 85 or 90 per cent. dry year.

A city which has a great reservoir which cannot be exhausted in less than from four to six years is fully warranted in continuing to use water from such a source until the safe capacity of the source, based upon past experience, has been materially exceeded, because if the extremely dry period arrives there is sufficient time to obtain an additional supply, or at least an emergency supply.

The speaker does not agree with Mr. Hazen's view that the method followed by the committee is based upon the "erroneous assumption that the dry periods of the past will be repeated from time to time in the future." There is no evidence of any permanent increase or decrease in the annual amount of rainfall, and it therefore seems far from erroneous to make the assumption stated.

The existing records show that the recent dry period includes the driest year and the driest period in the last sixty-four years, but this is not a long enough time to insure that drier periods will not occur. It is for this reason that it may in some cases be necessary for safety to assume the occurrence of still drier periods, but this is not a suitable basis for the view that the dry periods of the past will not recur.

The speaker does not agree with Mr. McKenzie's reason for the yearly excess of run-off from the Esopus drainage area as compared with that of other drainage areas. The conditions mentioned by him as favorable to a large run-off, if they are controlling, ought to be operative in the dry portions of the year as well as at other times, and yet the records of the minimum flow of different drainage areas for periods ranging from one week to three months, as given in Table 29, show that the Esopus and other Catskill Mountain areas yield rather less water during such portions of the year than ordinary streams.

Mr. Horton, in his criticism of the committee's report, appears to lay special stress upon the desirability of collecting "a mass of data giving the natural minimum yield, if only for a few days in each case, of a large number of small watersheds, such as are commonly used as sources of gravity water supply in New England." The committee furnished such data upon this point as was available at the time of making the report, and has added at the end of the report an additional record based upon the discharge of a stream in the latter part of 1914. The committee did not think, however, that the records for short periods had as much value as those for longer periods, for the reason that it is impossible to predict that extremely dry periods of a few days, or even of a few months, may not be followed by very much drier periods in the future. The committee, therefore, emphasized in its report the view that dependence should not be placed on the recorded minimum flow of small streams for short periods, but that storage should be provided to tide over such periods, even if the flow in the future should be much smaller than anything preciously recorded.

Mr. Johnson refers to the yield of swamp areas as being in some cases an important factor of the total yield of drainage areas, and asks whether the percentages used by the committee are based on measurements or are simply a matter of judgment. They are simply a matter of judgment, because no experimental information was at hand to show how much water evaporates from swamps. It has been the rule in the past, when making computations of the yield of drainage areas, to ignore the difference between the yield of swamps and other land surfaces, and the committee thought it better to take into account the smaller

yield from swamps, even though the correction was necessarily based on judgment. It was better to make a correction which might not be at all precise rather than not to make any.

The assumption was made in the report that undrained swamps might be considered as equivalent to 40 per cent. of water surfaces and 60 per cent. of upland surface, and in the case of drained swamps 30 per cent. was used in place of the 40 per cent. These percentages were intended to represent the average swamp of New England, a large proportion of such swamps containing trees and bushes and becoming reasonably dry in the hot weather of summer.

Mr. Johnson appears to refer to swamps of a different character, in which water is standing and meadow grass is growing. The evaporation from such areas would undoubtedly be much larger than is provided for by the rule of the committee.

The evaporation experiments by Mr. FitzGerald show that during the five months from May to September inclusive, there is on an average 25.6 in. of evaporation from water surfaces. It does not seem probable that as much water as this would be available for evaporation from the surface of most swamps, or that so great an amount of water would be evaporated from wooded swamps which are fairly dry during a part of these months.

The speaker agrees with Mr. Johnson that more information as to the yield of swamps is desirable.

As to the question of evaporation from water surfaces, it is well known that the amount per month differs from one year to another, as stated by Mr. Johnson, and the suggestion of the committee that average monthly results may be used without serious error was based upon the fact that the monthly evaporation in any given year does not as a rule vary widely from the average for a series of years, and the water surfaces to which the evaporation is applied are generally only a small fraction of the whole surface of the drainage area.

As suggested by Mr. Barrows, further light on the subject of evaporation from water surfaces is desirable, and the results obtained in Maine and at Rochester are lower than those obtained by Mr. FitzGerald. A part of this difference can be accounted for by the difference in temperature.

PROCEEDINGS.

HOTEL BRUNSWICK, BOSTON, MASS.,
November 11, 1914.

President Frank A. McInnes in the chair.
The following members and guests were present:

MEMBERS.

L. M. Bancroft, F. A. Barbour, A. E. Blackmer, J. W. Blackmer, R. L. Cochran, C. A. Bogardus, E. C. Brooks, Fred. Brooks, W. H. Butler, J. C. Chase, R. D. Chase, J. E. Conley, J. H. Cook, G. K. Crandall, E. D. Eldredge, A. L. Fales, G. H. Finneran, F. F. Forbes, F. B. Forbes, Patrick Gear, H. T. Gidley, Albert S. Glover, F. E. Hall, A. R. Hathaway, T. G. Hazard, Jr., D. A. Heffernan, A. C. Howes, H. C. Ives, H. R. Johnson, E. W. Kent, Willard Kent, G. A. King, F. A. McInnes, Thomas McKenzie, Hugh McLean, A. E. Martin, W. E. Maybury, John Mayo, William Naylor, F. L. Northrop, T. A. Peirce, H. E. Perry, Dwight Porter, A. L. Sawyer, W. B. Schwabe, J. E. Sheldon, C. W. Sherman, E. C. Sherman, G. H. Snell, G. A. Stacy, G. T. Staples, W. F. Sullivan, W. C. Tannatt, Jr., R. J. Thomas, D. N. Tower, C. H. Tuttle, Ernest Wadsworth, R. S. Weston, G. C. Whipple, J. C. Whitney, F. I. Winslow, G. E. Winslow. — 62.

ASSOCIATES.

Ashton Valve Company, by H. H. Ashton; Builders' Iron Foundry, by A. B. Coulters; Chapman Valve Manufacturing Company, by J. J. Hartigan; *Engineering News*, by I. S. Holbrook; *Engineering Record*, by N. C. Rockwood; Hersey Manufacturing Company, by Albert S. Glover, S. B. Greene; Lead Lined Iron Pipe Company, by T. E. Dwyer; Ludlow Valve Manufacturing Company, by A. R. Taylor and G. A. Miller; H. Mueller Manufacturing Company, by G. A. Caldwell; National Meter Company, by J. G. Lufkin and H. L. Weston; National Water Main Cleaning Company, by B. B. Hodgman; Neptune Meter Company, by H. H. Kinsey and R. C. Wertz; Pitometer Company, by E. D. Case; MacBee Cement Lined Pipe Company, by J. D. MacBride; Rensselaer Valve Company, by F. S. Bates and C. L. Brown; Ross Valve Manufacturing Company, by William Ross; A. P. Smith Manufacturing Company, by F. L. Northrop; Standard Cast-Iron Pipe and Foundry Company, by W. F. Woodburn; Thomson Meter Company, by E. M. Shedd; Water Works Equipment Company, by W. H. Van Winkle, Jr.; R. D. Wood & Co., by H. M. Simons; Henry R. Worthington, by Samuel Harrison. — 27.

GUESTS.

Thomas G. O'Connell, water commissioner, Wakefield, Mass.; Max von Recklinghausen and R. E. Case, New York, N. Y.; J. N. Smith, Wollaston, Mass.; George Smith, Norwood, Mass.; George H. Smith, F. M. Bates, Boston; Prof. L. Mitchell, Syracuse, N. Y.; James S. Davine, chairman water board, Westfield, Mass.; Harrison B. Freeman, president Northern Connecticut Light and Power Company, Thompsonville, Conn.; Stanley Osborne, M.D., W. R. Holway, LeRoy M. Peterson, Harriet Pack, Forest Funk, H. E. Berger, E. H. Magoon, T. R. Kendall, M. W. Cowles, Frances Lord; Aimi Caismion; C. E. Buck, G. S. Fowler, E. S. Tisdale, S. L. Tolman, R. V. Tiffany, Huet Massie, and P. Masucci, Boston, Mass — 28.

The Secretary presented the following applications for membership, properly endorsed and recommended by the Executive Committee:

Bernard F. Rogers, Charlestown, Mass., master plumber, foreman Boston Water Department, Water Service; William T. Lenehan, Dorchester, Mass., foreman City of Boston Water Service; S. Nishioeda, Tokio, Japan, Tokio Municipal Water Works; Estus H. Magoon, Dorchester, Mass., assistant professor of hydraulic and scientific engineering, Massachusetts Institute of Technology; Ernest B. Black, Kansas City, Mo., engaged in water supply and purification particularly; Walter H. McMahon, Chelmsford, Mass., superintendent of the water district; Elmer G. Manahan, Mt. Vernon, N. Y., had charge of filtration division, Department of Water Supply, Gas, and Electricity, New York City, now in charge of designing division of this department; Thomas E. Lally, Boston, Mass., engineering work in Boston Water Department; George A. Stowers, Billerica, Mass., assistant engineer water pipe, superintendent of water department; William F. Clark, Winchendon Mass., superintendent water works; Frederic H. Fay, Boston, Mass., consulting engineer, Fay, Spofford & Thorndike; Edward F. Hughes, Watertown, Mass., water commissioner; Frederick L. Waldmyer, Winchester, Mass., water registrar; Raymond J. Andrus, Montesano, Wash., vice-president and general manager Northwest Electric and Water Works; M. Cashman, Newburyport, Mass., contracting, has done practically all building of filter beds, reservoirs, and laying pipes for the Newburyport Water Works for the past twenty years; Sturgis H. Thorndike, Boston, Mass., consulting engineer; Charles M. Spofford, Boston, Mass., consulting engineer; James Fitzgerald, West Acton, Mass., superintendent of water supply district; A. H. Grindle, Bar Harbor, Me.. superintendent Bar Harbor Water

Company; George O. Adams, North Andover, Mass., chemist with State Department of Health; Harold P. Buttenheim, editor of *The American City*, New York City; Power Equipment Company, T. H. Holmes treasurer, Boston, Mass.; H. F. Jenks Co., Inc., Pawtucket, R. I.; William T. Dotten, Winchester, Mass., superintendent water works,— applicant for reinstatement.

On motion the Secretary was directed to cast the ballot of the Association in favor of the applicants, and he having done so they were declared duly elected members of the Association.

THE PRESIDENT. There is one thing I would like to say. The Executive Committee are now considering the question of the meeting place for the annual convention of next year. Their mind is entirely open in the matter, and the Executive Committee as a whole would welcome suggestions. After the meeting is over, in the hotel and corridor, we would be delighted to hear suggestions; or write to any member of the committee just what you think about it.

The first paper of the afternoon was entitled "Sterilization of Water with Ultra-Violet Rays," by Max von Recklinghausen, Ph.D., Strassburg. After reading his paper Dr. Recklinghausen answered questions by Mr. John C. Whitney and Mr. Tannett of Easthampton.

"The Use of Ozone as a Sterilizing Agent for Water Purification" was the subject of a paper by Sheppard T. Powell, chemist Baltimore County Water and Electric Company. Mr. Powell not being present, his paper was read by Mr. F. B. Forbes. The author of the paper being absent, the President did not invite discussion upon it.

The next paper on the program was entitled "Water Rates," by B. M. Wagner, C.E., Rockville Center, N. Y. Mr. Wagner was not present, and as the paper was in print and will be published in the JOURNAL, the President declared it read by title.

The topical discussion was on the general subject of Service-Pipes, — methods used; methods of making connection at main; depth of laying; troubles from freezing; methods of thawing, etc. The discussion was opened by Mr. E. C. Brooks and Mr. F. F. Forbes, and the following-named gentlemen participated in it: George H. Finneran, George A. King, John H. Flynn,

William Naylor, John C. Whitney, Charles W. Sherman, Lewis M. Bancroft, R. D. Chase, D. A. Heffernan, G. A. Caldwell, George A. Stacy, Robert S. Weston, W. F. Sullivan, T. G. Hazard, Jr., Edward D. Eldredge, Patrick Gear, George E. Winslow.

HOTEL BRUNSWICK, BOSTON, MASS.,
December 9, 1914.

President Frank A. McInnes in the chair.
The following members and guests were present:

MEMBERS.

A. F. Ballou, L M. Bancroft, F. A. Barbour, G. W. Batchelder, A. E. Blackmer, J. W. Blackmer, C. A. Bogardus, Dexter Brackett, E. C. Brooks, G. A. Carpenter, George Cassell, J. C. Chase, R. C. P. Coggeshall, F. L. Cole, J. E. Conley, A. W. Cuddeback, G. W. Cutting, Jr., F. W. Dean, E. R. Dyer, E. D. Eldredge, G. F. Evans, F. F. Forbes, Albert S. Glover, Clarence Goldsmith, J. W. Graham, R. K. Hale, F. E. Hall, E. A. W. Hammatt, C. R. Harris, L. M. Hastings, T. G. Hazard. Jr., D. A. Heffernan, D. J. Higgins, A. W. Jepson, W. S. Johnson, Willard Kent, G. A. King, J. J. Kirkpatrick, F. A. McInnes, Hugh McLean, W. H. McMahon, John Mayo, J. H. Mendell, F. E. Merrill, G. F. Merrill, H. A. Miller, F. L. Northrop, T. A. Pierce, H. E. Perry, D. C. Randall, C. L. Rice, L. C. Robinson, W. J. Sando, C. M. Saville, A. L. Sawyer, J. E. Sheldon, H. H. Sinclair, G. H. Snell, G. T. Staples, W. F. Sullivan, R. J. Thomas, E. J. Titcomb, D. N. Tower, C. H. Tuttle, W. H. Vaughn, R. S. Weston, G. C. Whipple, F. B. Wilkins, F. I. Winslow, I. S. Wood.—70.

ASSOCIATES.

Builders' Iron Foundry, by A. B. Coulters and A. A. Wood; Chapman Valve Manufacturing Company, by J F. Mulgrew; Darling Pump & Manufacturing Co. (Ltd.), by J. L. Hough and H. A. Snyder; *Engineering Record*, by I. S. Holbrook; *Engineering News*, by N. C. Rockwood; Hersey Manufacturing Company, by Albert S. Glover, Walter A. Hersey, S. G. Greene; Kennedy Valve Company, by M. J. Brosnan; Lead Lined Iron Pipe Company, by T. E. Dwyer; Ludlow Valve Manufacturing Company, by J. H. Caldwell and A. R. Taylor; MacBee Cement Lined Pipe Company, by J. D. MacBride; H. Mueller Manufacturing Company, by G. A. Caldwell; National Meter Company, by J. G. Lufkin and H. L. Weston; National Tube Company, by H. T. Miller; Neptune Meter Company, by H. H. Kinsey; Pittsburgh Meter Company, by J. W. Turner; Platt Iron Works Company, by F. H. Hayes; Rensselaer Valve Company, by C. L. Brown and F. S. Bates; A. P. Smith

Manufacturing Company, by F. L. Northrop; Standard Cast-Iron Pipe and Foundry Company, by W. F. Woodburn; Union Water Meter Company, by F. E. Hall and E. K. Otis; Water Works Equipment Company, by W. H. Van Winkle, Jr.; R. D. Wood & Co., by H. M. Simons; Henry R. Worthington, by Samuel Harrison and E. P. Howard.—33.

GUESTS.

S. D. Soule, superintendent Gardiner Water District, Gardiner, Me.; Arthur E. Weeks, New Bedford, Mass; George A. Stowers, superintendent water works, Billerica, Mass.; N. B. Tower, R. B. Tower, Cohasset, Mass.; Donald Green, assistant engineer, Greenfield, Mass.; Frank Bates, Boston; Smith F. Ferguson, New York, N. Y.—8.

The Secretary presented the following applications for membership, properly endorsed and recommended by the Executive Committee:

Resident: Oliver E. Williams, Boston, Mass., vice-president of the Tiffin, Ohio, Water Works; M. W. Carroll, Millers Falls, Mass., water commissioner of the Millers Falls Water Supply District; Roland F. Kay, Milford, Mass., meter inspector, Milford Water Works; Walter N. Charles, New Bedford, Mass., New Bedford Sewage Disposal Plant; George F. Ashton, Salem, Mass., city engineer; H. E. Crowell, Haverhill, Mass., superintendent water works; William A. Tripp, Vineyard Haven, Mass., engineer for Tisbury Water Works; Isaac Osgood, Boston, Mass., electrical and fire insurance engineer; Leon Edward Dix, Northfield, Vt., assistant professor of civil engineering, Norwich University; Moses L. Brown, Quincy, Mass., commissioner of public works; Eugene Carpenter, Newton, Mass., constructor of water supply plants; C. W. Whiting, Boston, Mass., consulting engineer; J. Harold Remick, Littleton, Mass., superintendent of water works and municipal light plant; John G. Whitman, Quincy, Mass., superintendent water works.

Non-resident: Henry W. Taylor, Albany, N. Y., assistant engineer, City of Rochester, N. Y., and New York Department of Health, and consulting engineer for various municipalities; R. C. Harris, Department of Water Works, Toronto, Canada; S. F. Ferguson, New York City, member of the firm of Nicholas S. Hile & S. F. Ferguson, consulting engineers; Philip Burgess, Columbus, Ohio; and R. C. Harris, Toronto, Ontario.

The Secretary was directed to cast the ballot of the Association in favor of the applicants, and he having done so they were declared duly elected members of the Association.

The first paper of the afternoon was entitled "A Description of the Water Supply System of Cohasset, Mass.," by D. N. Tower, superintendent of the Water Company at Cohasset, Mass. The paper was discussed by Mr. Robert S. Weston, Mr. Hugh McLean, and Mr. W. S. Johnson. The paper was accompanied by stereopticon pictures showing various features of the Cohasset Water Works and also views of the town.

The second paper of the afternoon was entitled "The Greenfield Water Works," and was read by Mr. George F. Merrill, superintendent of the Greenfield Water Works. This paper also was accompanied by a considerable number of interesting views.

The topical discussion (continued from the November meeting) was on the general subject of "Service Pipes, — methods used; methods of making connection at main; depth of laying; troubles from freezing; methods of thawing, etc." The following-named gentlemen participated in the discussion: R. C. P. Coggeshall, George Cassell, Allen W. Cuddeback, D. A. Heffernan, Robert J. Thomas, F. F. Forbes, I. S. Wood, Frank B. Wilkins, Robert S. Weston.

Adjourned.

EXECUTIVE COMMITTEE.

Meeting of the Executive Committee of the New England Water Works Association at headquarters, Tremont Temple, Boston, Mass., Wednesday, November 11, 1914.

Present: President Frank A. McInnes, and members William F. Sullivan, Samuel E. Killam, Richard K. Hale, Lewis M. Bancroft, George A. King, and Willard Kent.

Active: Bernard F. Rogers, foreman Public Works Department, Boston, Mass.; William T. Lenehan, foreman Water Service, Public Works Department, Boston, Mass.; S. Nishioeda, Tokio Municipal Office, Water Works Department, Tokio, Japan; Estus H. Magoon, assistant professor of hydraulic and sanitary engineering, Massachusetts Institute of Technology, Boston, Mass.; Ernest B. Black, consulting engineer, Kansas City, Mo.; Walter H. McMahon, superintendent water works, Chelmsford, Mass.; Elmer G. Manahan, division engineer, Department of Water Supply, New York, N. Y.; Thomas E. Lally, assistant engineer, Public Works Department, Water Service, Roslindale, Mass.; George A. Stowers, superintendent water works, Billerica, Mass.; William F. Clark, superintendent water works, Winchendon, Mass.; Frederic H. Fay, consulting engineer, Fay, Spofford & Thorndike, Boston, Mass.; Edward F. Hughes, water commissioner, Watertown, Mass.; Frederick L. Waldmyer, water registrar, Winchester, Mass.; Raymond J. Andrus, general manager Northwest Electric and Water Works, Montesano, Wash.; M. Cashman, 63½ Water Street, Newburyport, Mass.; Sturgis H. Thorndike, consulting engineer, Fay, Spofford & Thorndike, Boston, Mass.; Charles M. Spofford, consulting engineer, Fay, Spofford & Thorndike, Boston, Mass.; James Fitzgerald, superintendent water works, West Acton, Mass.; A. H. Grindle, superintendent Bar Harbor Water Company, Bar Harbor, Me.; George O. Adams, chemist, State Department of Health, Experiment Station, Lawrence, Mass. — 20.

Associates: *The American City*, New York, N. Y.; Power Equipment Company, Boston, Mass.; H. F. Jenks Co., Inc., Pawtucket, R. I. — 3.

Twenty applicants for Active and three for Associate membership were, by vote, recommended therefor.

One (1) applicant for reinstatement was, by vote, reinstated, and one applicant for active membership was, by vote, rejected as ineligible therefor under the Constitution of the Association.

Adjourned.

Attest: WILLARD KENT, *Secretary.*

Meeting of the Executive Committee of the New England Water Works Association at headquarters, Tremont Temple, Boston, Mass., Wednesday, December 9, 1914.

Present: President Frank A. McInnes, and members William F. Sullivan, Robert J. Thomas, Samuel E. Killam, Richard K. Hale, Lewis M. Bancroft, George A. King, and Willard Kent.

Active: J. Harold Remick, superintendent water works and municipal light plant, Littleton, Mass.; C. W. Whiting, consulting engineer, 33 Broad St., Boston, Mass.; Eugene Carpenter, Newton, Mass.; Moses L. Brown, commissioner of public works, Quincy, Mass.; Leon Edward Dix, associate professor of civil engineering, Norwich University, Northfield, Vt.; Isaac Osgood, engineer, Boston Board of Fire Underwriters, 36 Osgood St., Andover, Mass.; Henry W. Taylor, hydraulic and sanitary engineer, 100 State St., Albany, N. Y.; William A. Tripp, engineer Tisbury Water Works, Vineyard Haven, Mass.; H. E. Crowell, superintendent water works, Haverhill, Mass.; George F. Ashton, city engineer, Salem, Mass.; Walter N. Charles, civil engineer, 176 Clinton St., New Bedford, Mass.; Roland F. Kay, meter inspector, Milford Water Works, Milford, Mass.; M. W. Carroll, water commissioner, Millers Falls, Mass.; S. F. Ferguson, 100 William St., New York, N. Y.; Oliver E. Williams, vice-president Tiffin, Ohio, Water Works, 67 Milk St., Boston, Mass.; John G. Whitman, superintendent water works, 104 Penn St., Quincy, Mass.; Philip Burgess, 8 East Long St., Room 826, Columbus, Ohio; and R. C. Harris, Department Water Works, Toronto, Ontario. — 18.

Eighteen applicants for membership were received, and the applicants were by unanimous vote recommended therefor.

Three (3) applicants were reinstated to membership, they having complied with the requirements of the Constitution.

Voted: That the annual meeting, January 13, 1915, be Ladies' Day, and that the President and Secretary by a committee to arrange therefor.

Adjourned.

Attest: WILLARD KENT, *Secretary.*

Meeting of the Executive Committee of the New England Water Works Association at headquarters, Tremont Temple, Saturday, December 26, at 2 o'clock P.M., pursuant to call of the President.

Present: President Frank A. McInnes, and members Leonard Metcalf, Carleton E. Davis, Robert J. Thomas, Samuel E. Killam, Lewis M. Bancroft, and Willard Kent.

A communication from Mr. E. B. Rosa, Secretary Joint National Committee on Electrolysis, inviting the Association to membership in that organization, was presented and, on motion of Mr. Metcalf, seconded by Mr. Thomas, it was voted that it was inadvisable for this Association to take active official participation in their work at this time.

A report of the committee on last annual convention was presented and accepted, and President Frank A. McInnes, Messrs. Charles W. Sherman, and Frank A. Barbour were made a committee to consider the question of the manner of raising funds for future conventions.

On motion of Mr. Thomas it was voted to hold the next annual convention at the White Mountains.

Adjourned.

Attest: WILLARD KENT, *Secretary.*